COASTAL
Collaborative Land-Sea Integration Platform

# Deliverable D13 Pilot SD Models for Coastal-Rural Interactions - Case Study Level

Final Version

WP 4, T 4.2
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| Dissemination level | | |
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| **PU** | Public | **X** |
| **CO** | Confidential, restricted under conditions set out in Model Grant Agreement | |
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| Deliverable type | | |
|---|---|---|
| **R** | Document, report | **X** |
| **DEM** | Demonstrator, pilot, prototype | |
| **DEC** | Web sites, patent fillings, videos, etc. | |
| **OTHER** | Software, technical diagram, etc. | |

**History**

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## Executive summary

This is the status report for the progress made with the design and implementation of the pilot land-sea models by the Multi-Actor Labs (MALs) during the first 24 months of the COASTAL project which also consists of a detailed description of how the MALs translated the problem scope for their regions (deliverable D12) and stakeholder analyses (deliverables D3 and D4) into stock-flow models. System Dynamics (Sterman, 2000) was selected as modelling framework based on the graphical transparency of this type of modelling, the direct translation of problems into model structures, consideration of systemic limitations, appropriateness for including human and social aspects directly in the models, and the limited computational requirements – making these models particularly useful for interactive use by and with stakeholders.

In this report we first present the methodology that was used to transfer the analysis from WP1 that resulted in a number of mind maps and causal loop diagrams (CLD) into a system dynamics pilot model design. Separate chapters are devoted to each MAL, describing how this general methodology was applied. To conclude, we provide a synthesis section in which the general status of the MAL models is summarised and in which we provide an outlook for the oncoming challenges in the modelling process.

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## Abbreviations and acronyms

| | |
|---|---|
| CLD | Causal Loop Diagram |
| LSI | Land-Sea Interaction |
| MAL | Multi-Actor Lab |
| REA | Research Executive Agency |
| SD | System Dynamics |
| SF | Stock-Flow |

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# 1 Introduction

## *System dynamics modelling*

Systems Dynamics (SD) modelling 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 an SD-based modelling approach is used 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 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 is capable of providing 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.

## *How does this work relate to the rest of the project?*

The responsibility for developing, validating and applying System Dynamics (SD) models for land-sea interactions lies with Work Package 4 (Systems Modelling). The SD models will be used to formulate and support strategic business and policy analyses aimed at improving coastal-rural synergies. To achieve this, separate SD models of the coastal-rural interactions were developed for each case study, starting from the qualitative understanding of these interactions developed in WP1. The qualitative analysis in WP1 resulted in a set of Mind Maps and Causal Loop Diagrams (CLD) describing the different interactions identified for each of the MAL. As the original CLDs were too complex, the overall CLD resulting from WP1 were divided into a number of smaller problems that were translated into individual System Dynamic (SD) models. In this deliverable we describe on a MAL by MAL basis the conversion of the CLD into a set of SD models. For each of the MALs, we present the major issues that were identified for the MAL which is the model scope for the SD models, the reasoning used to transform the CLD to an SD model and the scientific concepts on which this is based, the SD model structure and its main variables and clarify the scope of the model by listing the kind of questions that can be addressed with the model . Work Package 2 (Model and Data Inventory) and

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Work Package 4 (Systems Modelling) are crucial for the COASTAL project to ensure the business road maps and policy guidelines are scientifically founded and made evidence-based. Quantification of the mental models of stakeholders and actor partners into stock-flow models has several important advantages: the consistency of conceptual analyses can be verified and increased, reuse and exchange of knowledge is facilitated and a toolbox for analysing the social-economic, environmental, physical and administrative land-sea interactions becomes available. Supportive in-depth, thematic expertise and data are being collected by Work Package 2 whereas Work Package 4 focuses on the System Dynamics (SD) modelling itself.

## *Purpose and structure of the deliverable*

This deliverable describes for the different MALs the pilot SD models that were developed based on the problems that were identified in the CLDs produced by WP1. The term 'pilot model' is in the context of this work used to describe a model which addresses all the problems represented in the CLD that we want to address with the SD modelling and for which the SD structure is fully defined in Vensim. This in-breadth approach where all problems that need to be addressed in the SD modelling are considered contrast to an in-depth approach where a model is completely elaborated down to testing and running scenario's for only part of the problems described by the CLD. The reason, for adopting an in-breadth strategy where we first define the complete structure of the SD model is favoured here to ensure that all interactions between subdomains are considered from the beginning. Indeed, interactions are at the core of the project so an oversight of interactions by focusing on subdomains would result in having to reconsider the structure of fully developed models at a later stage when these need to be combined or extended with models for other domains. Another reason for favouring an in-breadth approach is that one of the challenges faced in WP4 is that most of the MALs involved found it very difficult to delineate the problems that needed to be considered in the modelling. Most, if not all, modellers involved have a mechanistic modelling background in which a full description of the system down to the last detail is considered essential to arrive at a meaningful model. This detailed problem breakdown contrasts with normal system dynamics practice and impedes fast prototype development. By requesting from each MAL explicitly what problems the modelling is intended to focus on we hope to set the stage as to facilitate implementation afterwards. Finally, an in-breadth approach is also preferable for the tasks in WP3 and WP5 that require that the problem domain for the modelling in each MAL is well delineated. Not providing a comprehensive model structure would imply that the problem domain that WP3 and WP5 are based on would be evolving continuously. While changes of scope can also in an in-breadth current approach not be completely ruled out, they are not inherent to the methodology which is the case of an in-depth approach.

Depending on the complexity of the models and problem scope the models differ in terms of the degree of quantitative implementation (equations, non-linear functions and parameterization). The first priority was to harmonize the modelling process across the MALs and provide and integrative framework for the interactions between the narrative and conceptual WPs (WP1, WP3 and WP5) and quantitative WPs (WP2 and WP4). In the next chapters we will therefore first present the general methodology that will be applied

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to translate the CLD and stakeholder/actor feedback established in WP1 into a SD model design. This methodology will then be applied to the individual MALs and for each MAL we will sequentially describe:

1. The problem scope and land sea interactions considered;
2. The CLD on which the model is based, indicating which parts are actually modelled and why other parts are not modelled. If the CLD deviates from the original CLD derived in WP1 we explain why this is the case;
3. The SD model structure(s) that can be used to describe the problem(s) that were identified;
4. A list of problems that can be modelled with the SD model structure;
5. An overview of the main variables of the SD model;
6. Data sources that were used in defining the SD model structure;
7. Planning for next steps. How do you expect to proceed based on the structure?

In the above list, 4 is not really necessary as a well-presented SD model structure in itself is an exact specification of the problems that can be solved with the model. The chapter is intended as a summary for non-modelers such as the MAL actors, stake holders and the WP3 and WP5 partners. Both the list of variables (5) and the inventory (6) can serve as input to WP2 that will help collect the equations and the data needed to populate the SD model in the next phase and to WP3 and WP5 that are aimed at setting the stage in which the models will be deployed.

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# 2 Methodology

The methodology adopted for the System Dynamics modelling starts with the results of the conceptual analysis done in WP1. For the conceptual analysis, six sector workshops were organised for each of the MALs (Tiller et al., 2019). Typically, in these sector workshops, 5-15 participants from a key coastal or rural sector were invited to present their concerns and priorities with respect to land-sea interactions. The workshops resulted in graphical models or 'mind maps' collecting all the relevant aspects of the land-sea interactions identified during the discussion by the participants. The results from the individual sectors were afterwards condensed into Causal Loop Diagrams (CLD) both at a sectoral level and as an overall CLD integrating the individual sectors. Besides the mind maps and CLDs, the requirements for the SD models were also distilled from the problem scope or future narratives for the different MALs and further consultation with MAL actors or experts that were considered relevant by these MAL actors. In some cases, this process, starting at the initial CLDs and further consultation steps, led to a revision of the set of problems that were initially identified as relevant to the MAL and reconsidering the set of problems that should be addressed in the modelling.

To assist in this process, early in the project WP4 identified seven relevant questions to be answered (see deliverable D12):

a) which problems and priorities can be defined?
b) who is affected by the problem, and who may be involved in causing it?
c) is the problem dynamic in nature?
d) are SD models appropriate tools for analysing and understanding these problem(s)?
e) what is the purpose of the model?
f) what level of detail is needed to describe the problem in the model?
g) what are the spatial, temporal, economic and other boundaries of the model, defining what to include?

In particular questions d-g are important for the design, implementation and use of stock-flow models.

Three important challenges are faced when converting the CLD to a SD model structure:

- To identify the relevant interactions to be quantified in the, often complex, causal loop diagrams;
- To identify the correct level of detail for the models with the correct stock and flow variables defining the general model structure;
- Data availability for setting input drivers, model parameters, systemic limitations and time delays.

The following steps outline the **general modelling strategy** starting from the CLD(s) resulting from the analysis in WP1:

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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 development of the pilot models as defined in this task of WP4 corresponds to the first 3 steps of the general modelling strategy. Some MALs have advanced their development even further and are for (parts of) their models starting with the calibration, testing and validation. The proposed strategy also allows for iteration and so testing and validation can and will most probably lead to changes in the original model structure derived from the CLD. Not explicitly mentioned here is the interaction with MAL actors and stakeholders in the model development process. At the end of the general modelling strategy also this will lead to the need for revisiting the pilot model structure.

Even though the CLDs for the MALs are themselves a condensed representation of the interactions that were identified, they are in general still too complex to be directly transformed into SD models. Indeed, the MAL CLD does not represent one single problem but a whole set of intertwined problems. It was therefor at the onset of the model development in M12 decided not to attempt to convert the whole CLD for the MAL directly into a single SD model. Instead we chose to distinguish smaller subsets of problems in the MAL CLD that together combine to describe the relevant problems of the CLD. This implies that the pilot SD models consist of a set of smaller SD models that each model parts of the problems defined by the MAL CLD. The advantage is that the development of these individual smaller models is easier to manage and that they can then be individually tested before they are integrated into one, single SD model for the MAL.

This bottom up approach where a complex model is set up step by step from smaller models that describe partial aspects of the Land-Sea Interactions (LSI) for the MAL is also better suited for gradually acquainting the MAL modelling teams with SD-modelling. Indeed, one of the main challenges during this task of WP4 was that most of the modelling teams had very different experience with modelling and only but a few of the participants were familiar with SD-modelling. SD-modelling, where the emphasis is on identifying problems and the dynamics these cause, requires a different mindset from process based, numerical modelling with which most modelers involved in COASTAL are familiar. Where the latter tends to describe in detail all the processes involved, the emphasis in SD modelling is on describing the problems generated by the dynamics (Sterman, 2000). The SD-model should therefore not be a complete representation of the system in all its detail, but a simplification of reality. Also, the fact that most modelling teams were not

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familiar with the Vensim software which was selected for the SD-modelling impeded a smooth adoption of the SD modelling process.

To organize the modelling, Work Package 4 assisted the MALs with modelling guidelines, group and individual support sessions (both face-to-face and online exchanges), model templates, examples and step-by-step illustrations of the modelling. In practice, to support the modelling process, the following were provided to the MAL participants:

- A first workshop during the General Assembly at Methoni was used to introduce System Dynamics modelling to the participants and the Vensim Software in May 2019. The presentations and a the generic Vensim model examples shown at the kick-off workshop were made available on the COASTAL participants portal. About half the workshop was organised as a hands-on session were participants used the freely available Vensim version to setup a model for a topic they were well familiar with. For most modelling teams this was either a water balance or water quality model;
- Regular bilateral Skype calls were regularly organised with the individual modelling teams of the MALs on a monthly basis. These were typically used to discuss specific modelling issues encountered for the MAL or when using Vensim. As time passed MALs would also send Vensim models that were then discussed in the Skype calls;
- To clarify problems identified during the Skype calls, small, generic models were used that were made available by both e-mail and the COASTAL partner area.
- Three group calls were organized to address common concerns or to present the next steps in the organisation of the model development;
- To support the organisation of the development different checklists were provided to the participants (Annex 1);
- An additional workshop with those involved in the modelling in WP4 was organised in January 2020 in Brussels, back to back with the first project review meeting at the Research Executive Agency (REA) in Brussels. At this workshop the different problems with the SD-methodology observed during the Skype sessions and mentioned by the different modelling groups were discussed and clarified.

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# 3 Pilot SD models for the MALs

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

### 3.1.1 Problem scope of the land sea system

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 1). A new Maritime Spatial Plan for the Belgian Coastal Zone for the period 2020-2026 was recently approved[1]. Figure 1 shows the dense use of space and complexity of combining offshore environmental and economic functions.

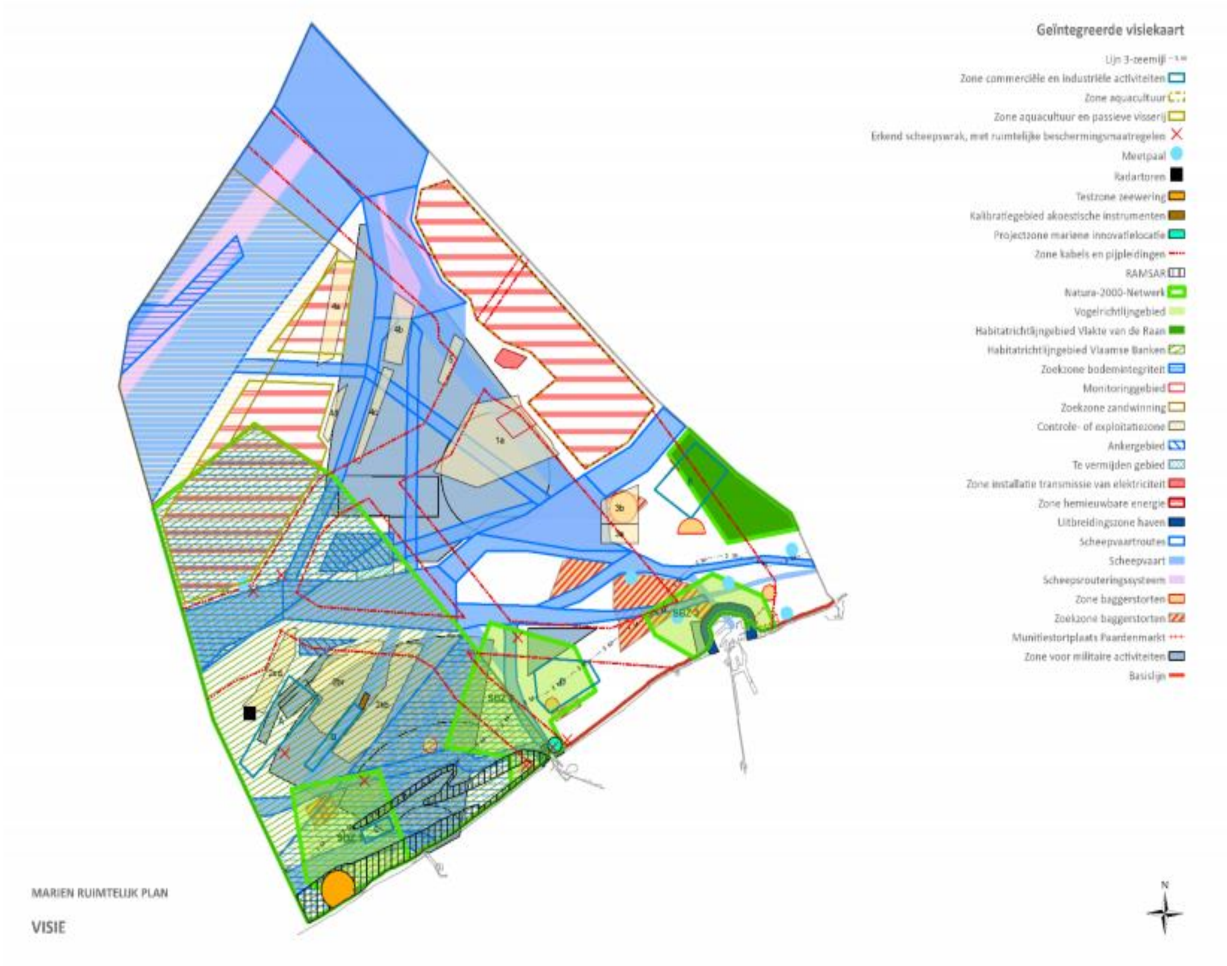


*Figure 1: Integrated Map as part of the new Marine Spatial Plan 2020-2026 for the Belgian Coastal Zone (Belgian Federal Public Service Health, Food Chain Service and Environment, 2019)*

[1] https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/msp-2020-englishtranslation.pdf

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Figure 2 and Figure 3 show the land use in the Belgian Coastal Zone with a 100 m resolution for the year 2013 and 2050 (Growth-As-Usual scenario) as modelled with the VITO RuimteModel[2]. The densely populated coastal zone is in contrast with the hinterland with a primarily agricultural function.

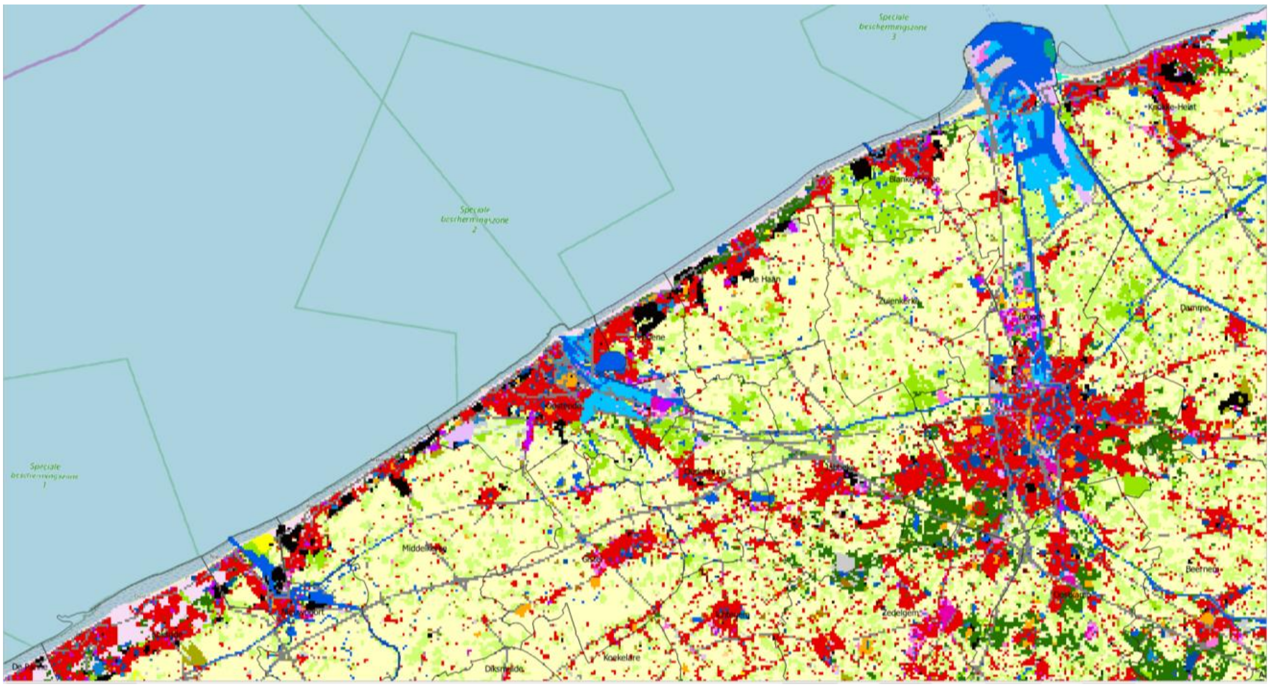

*Figure 2: Land use in the Belgian coastal zone (situation 2013) showing the build-up area (red)* [2]*.*

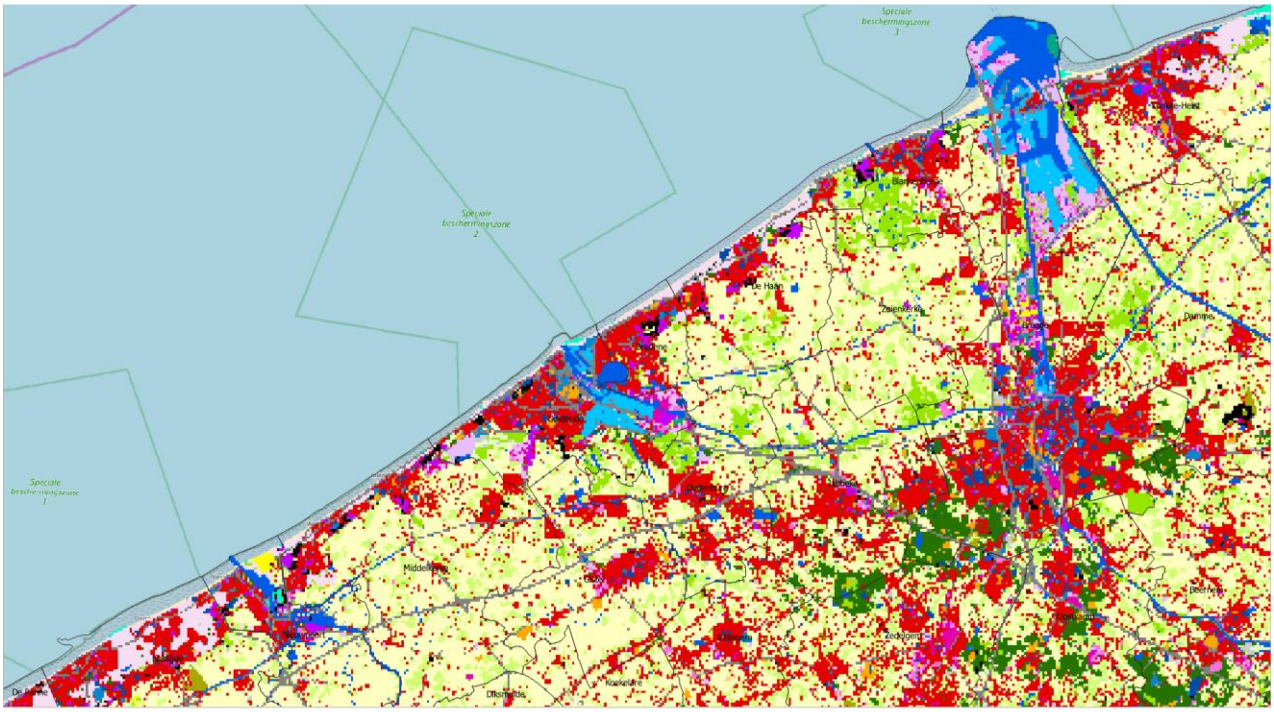

*Figure 3: Land use in the Belgian coastal zone (situation 2050 – Growth-As-Usual scenario) showing the build-up area (red).*[2]

[2] https://ruimtemodel.vlaanderen

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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 deep 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 target levels and contribute to coastal eutrophication. The quantities of fresh water are under pressure during extended periods of drought, because of multiple demands from industry, tourism, population and agriculture. A major stressor is the increasing salinization 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.

Potential land sea interactions to be considered for the Belgian Coastal Zone include:

- The amount and the quality of the water that is exchanged between the farming area in the coastal zone and the sea will be determined by climate change (sea level, rainfall, evapotranspiration), land use (farming, residential, nature) and population dynamics.
- The potential for wind energy and other uses of marine space and its effect on job creation and availability of skilled labour force, infrastructure and activities in the coastal zone

### 3.1.2 From Multi actor analysis to modelling

Figure 4 shows a high-level mind map of the main land-sea interactions identified during the sector workshops.

These interactions can be categorised in the following categories:

- Climate resilience: Impact of sea level rise and other effects of climate change on low lying inland farming land and nature and coastal safety;
- Port and energy: off shore energy production, storage and distribution coupled to employment and onshore infrastructure;
- Spatial and social transition: Impact of spatial planning, demography and tourism.

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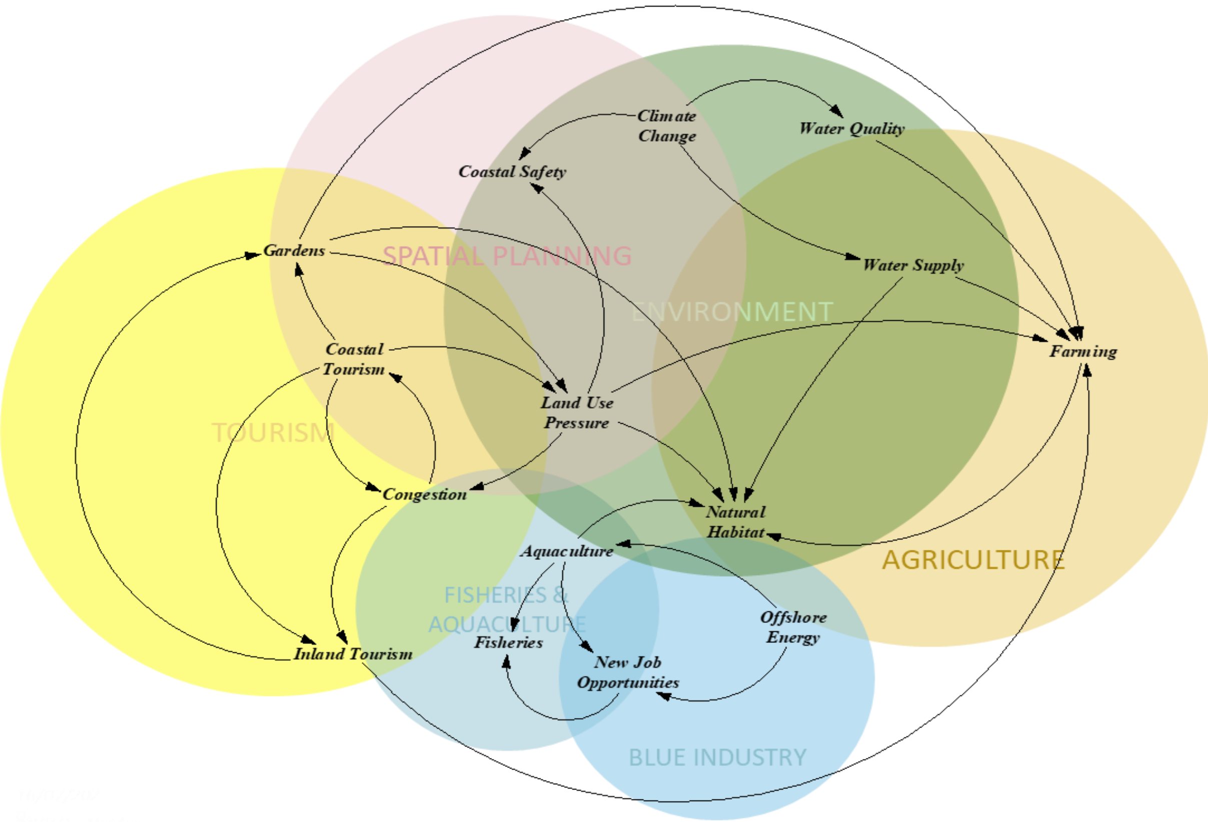


*Figure 4: Overview mind map with the main issues and linkages for the Belgian Multi-Actor Lab (project team analysis), showing the themes for the six sector workshops and overlap in issues raised.*

In Figure 5 we repeat the overall CLD which was reported by WP1 for MAL1. Although the

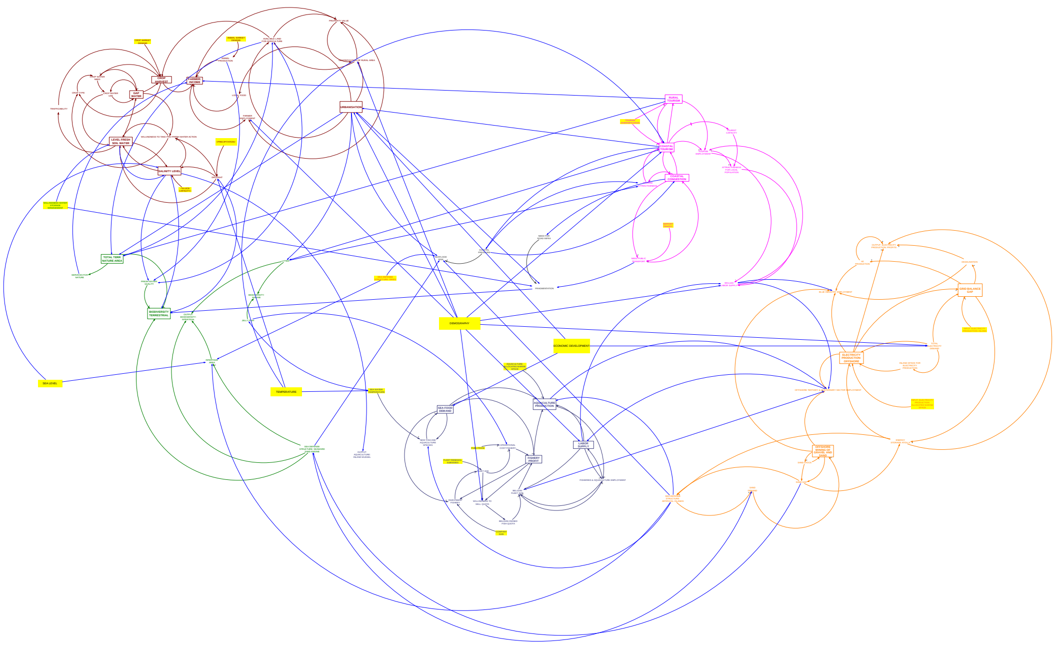

*Figure 5: Overall CLD for MAL1 as reported for WP1 in deliverable D3 the suggested stock variables are in boxes*

complexity and size of the CLD makes the figure illegible at this scale, it is clear that directly converting the whole CLD into a corresponding system dynamics model is unlikely to be a good idea. So instead of attempting to address all the problems outlined in the overall CLD in one single SD model we have identified two problem domains based on the interaction categories listed above:

- Climate resilience and polder management
- Port and offshore activities

Each of the next chapters starts with the model scope and the CLD that corresponds to that sub-model and then converts this information step by step into an SD model structure.

### 3.1.3 Pilot model 1 design: climate resilience and polder management

#### *3.1.3.1 Model scope of the polder model*

The model scope was determined together with VLM, the actor involved in the agriculture and environment sectors. Referring to the part of the CLD produced in WP1 that is relevant to the model scope (Figure 1), the model investigates the interaction between the land use (agriculture, nature) in the polder which strongly depends on the groundwater level of the polder and the different drivers such as climate change and demography and tourism in the coastal zone which have an effect on the amount of water available for the polder. In general, the number of active farmers in the polder is decreasing. When farms are sold these are often not bought by farmers but are converted to luxurious residences.

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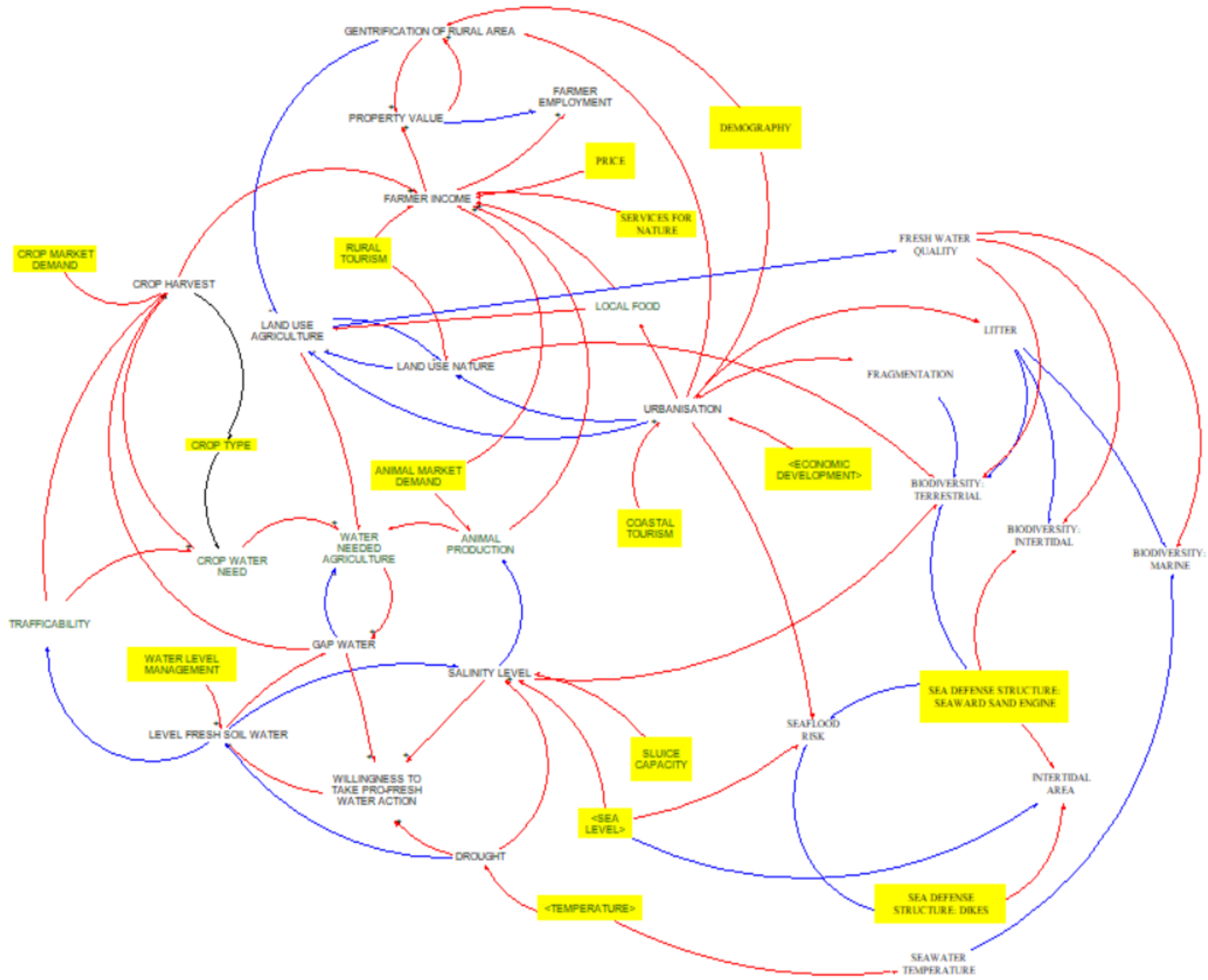


*Figure 6: Part of the MAL1 CLD that relates to the model scope (inputs are yellow).*

Aspects from the MAL1 CLD which are only indirectly related to the model scope such as ‘fisheries’ and ‘blue industry’ are not considered in this model. Tourism and demography are an input in this CLD and as such assumed to be unaffected by the processes described by the CLD for the current model. Variables related to climate change are included as input to the model and assumed to be independent of the processes in the model.

We convert this CLD into a SD model in 3 steps:

- the water management for the polder;
- agriculture and natural land use;
- biodiversity and flood risk.

In the next 3 chapter we’ll describe the steps and decisions taken to convert the concepts represented by the partial CLD to a SD model for each of these aspects

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#### 3.1.3.2 Quantification of the polder water level management

From the discussion with VLM a model for water management in the polder should contain the following processes:

- Climate change is expected to result in rising sea levels and in changing precipitation and evapotranspiration patterns. This could result in salinification and/or water logging of the low-lying polder near the coast which is used for farming and nature.
- A polder is a strongly managed system in which the water level in the ditches is set by adding and removing water to increase or lower the groundwater level.
- For the coastal polders in Flanders water is available from different sources such as surface water discharge of inland water such as rivers and canals, the effluent of the waste water treatment plant or water recovery from sealed areas such as the abundant caravan areas along the coast. While this water could be used as recharge to the polder it is also claimed for other uses such as drinking water production or the need to maintain a certain discharge in the canals for shipping and for avoiding salinification.
- There have been tests where water is buffered in creek mounds.
- To lower the groundwater level in the polder, the water manager will need to discharge water from the polder. While water is typically discharged gravitationally to the sea at low tides, rising sea levels could well mean that pumping will be needed in the future.
- According to the land use, potentially conflicting ground water management schemes are needed. For nature, a constant shallow groundwater level is preferred while for farm land the groundwater level should be lowered in spring to promote trafficability and kept high during summer time to sustain the crop. Therefore, depending on whether the water level management policy caters to the needs of the environment or the farming community a different management strategy will be needed.
- Salinification is mainly a problem for animal breeding.

While most of this is reflected in the partial MAL1 CLD (Figure 6) there are some differences which the original CLD neglects:

- There is a limited amount of water available for recharge to the polder from different sources.
- There are plans to buffer water.
- Water can also be removed by pumping.
- Water management is not only needed for farm land but also for nature.

To account for this the CLD was adapted (Figure 7).

The model calculation period is taken to be from 2010 to 2100. The discharge to sea is dependent on the tides which implies that an hourly time step is needed. To limit calculation time, it was however decided to not model the tidal effect explicitly and instead adopt a monthly time step to accommodate for the monthly changes in farm practice and the main climatological drivers.

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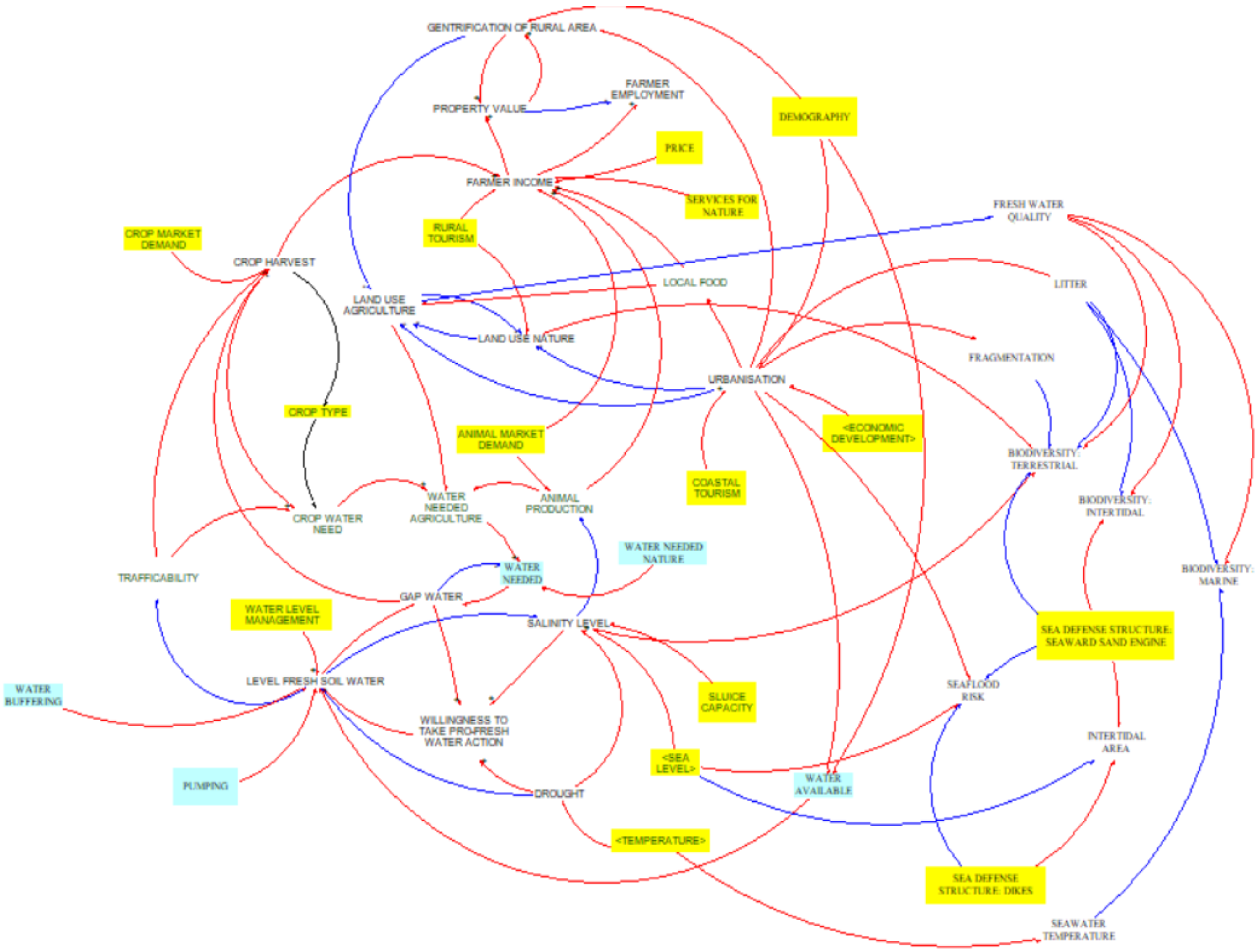


*Figure 7: Part of MAL1 CLD adapted (blue background) to include nature in polder water management, the different water sources available, the possibility of pumping for discharge and buffering. (inputs are yellow)*

The conversion of the CLD starts with the identification of the stock variable(s). Once these are identified we consider the flows that increase and decrease these stocks and what auxiliary variables are needed in the calculation process. In the text we have added references to the CLD variables in Figure 7 whenever possible. These can be recognized as they are in italic.

In the SD model that corresponds to the water management part of the CLD depicted in Figure 7 the main stock variable is the *level fresh soil water*. This corresponds to the phreatic ground water level and has been named the polder level in the SD model. Notice, that for the stake holders (farmers) the water level corresponds to the surface water level in the ditches which is different from the groundwater level which is considered in the SD model.

While not included explicitly in the CLD - assuming there is no human intervention - the polder level will rise due to precipitation. As a counterpart to precipitation, evapotranspiration (ET) will decrease

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the polder level. The CLD variables water needed for crops (crop water needed) and for nature (water needed nature) correspond to the ET. Depending on crop type (crop type) and relative area used for agriculture (land use agriculture) the total ET for the model area can be determined from the ET for crops and nature.

The possibility to increase the polder level depends on the *water available* and the amount needed. The latter is dependent on the difference between the polder level and the *desired* level where the *desired* level is set according to water level management and the willingness to take fresh water action. The *desired* level and the water needed are not shown in the CLD but are required in the SD model to correctly model the dynamics of the system. In case of the polder the difference between the desired and actual ground water level changes slowly due to the slow response of the groundwater level to changes in the water level in the ditches which is used to regulate that groundwater level. The difference between desired and actual water level will be used to calculate how much water needs to be added or removed. The SD model structure needed to model how *water level management* and *willingness to take fresh water action* decide how much water is used from the water available considering a delay in response is shown in Figure 8. The delay is modelled using a first order delay to the recharge inside the stock variable equation. The delay time increases with the resistance to water flow which physically can be related to the distance between the ditches in the polder and the hydraulic conductivity of the soil type of the polder

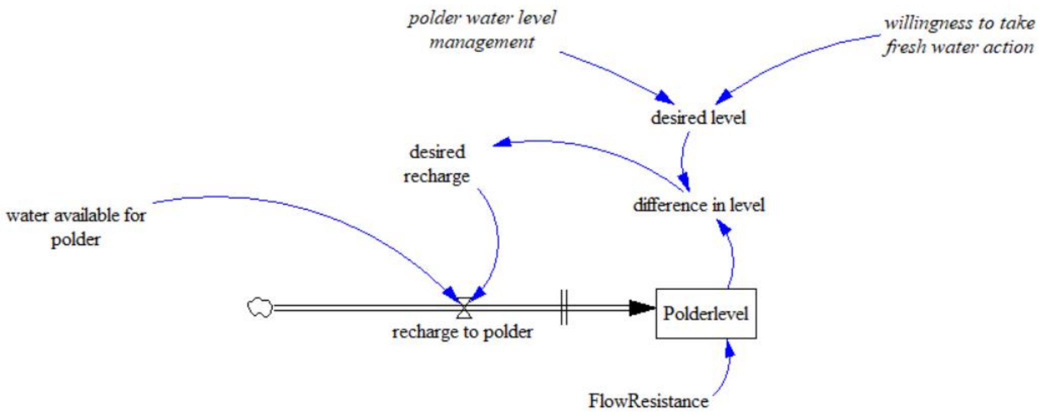


*Figure 8: SD model structure for the polder recharge management.*

Analogous to the recharge the discharge is determined by an amount of discharge wanted and the discharge capacity of the system. Looking at Figure 8 and considering the option that the desired level could be below the actual polder level the recharge structure can be naturally extended to also model discharge (Figure 9). To this structure we have also added based on literature a 'dischargeToAvoidSalinification' which is a minimum discharge which is needed to avoid salinification, and which is the minimum value of the desired discharge. By including dischargeToAvoidSalinification we will ensure that there will be discharge even when the desired level is above the actual level, assuming that there is enough discharge capacity off course.

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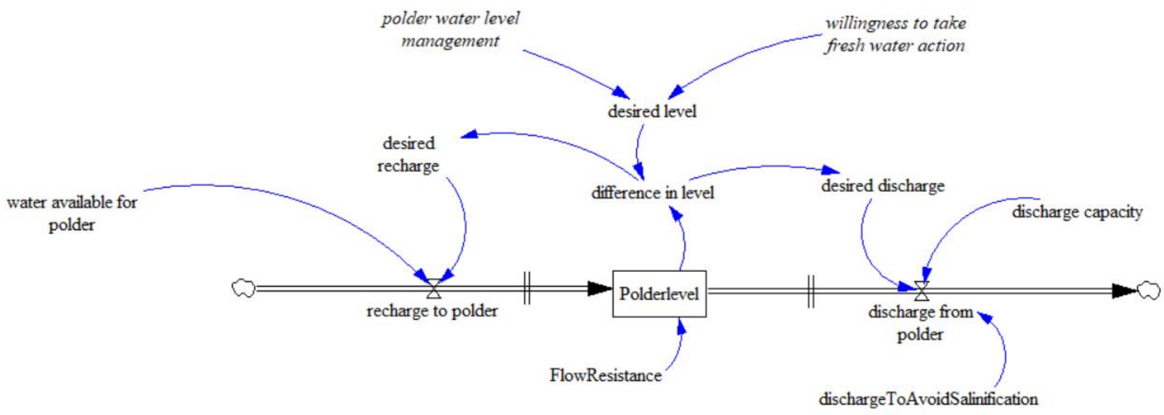


*Figure 9: Basic SD model structure for the polder water management.*

While the structure in Figure 9 is essentially what is required if one neglects precipitation and evapotranspiration the following considerations led to the final SD structure for the water management (Figure 10):

- In case the desired recharge is less than the water available for the polder, not all available water will be used. Water that is not used will be used for other purposes and/ or eventually discharged to the sea. This implies that the actual water discharge to the polder that is calculated from the available water will have a feedback on the water available itself. As long as we don't consider this feedback we can ignore the circularity in this calculation. However, if that is not the case we have to introduce a stock to the structure. This stock will correspond to a buffer that separates the water supply from its user (= the polder). While a buffer with zero capacity can be the solution to the circularity problem, for the polder water management we can also put this buffer to good use as there are plans to buffer water in the creek mounds in the polder. In the SD model structure, the water available is added to the buffer stock variable and removed by the recharge required by the polder. What is not removed can stay in the buffer up to buffer capacity. All above buffer capacity is added to the buffer loss which feeds the rest back to the available water calculation.

- In the final model the precipitation and ET have also been added as can be expected. Notice though that they are also connected to the recharge and discharge rate calculation. This is done to avoid what is called the steady state error. This can be understood by considering the balance equation of the stock for the polder level:
  $$Level_{new} = Level_{old} + (recharge - discharge + precipitation - ET) * TimestepLength$$
-
-

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- During steady state the level remains constant and $Level_{new}$ is equal to $level_{old}$. This implies that for steady state recharge-discharge = precipitation-ET should be true. From this we can further deduce that recharge = precipitation - ET and discharge = ET – precipitation should also be true. So, for a correct calculation and to ensure that the stock balance is maintained at all times the precipitation and ET should be added to the recharge and discharge calculations.
-
- The term *trafficability* is used to indicate to what extend farmland is accessible to machinery without this resulting in damage to the soil structure. Especially during the preparation of the field in spring and during harvest in autumn too wet soil conditions can result in reduced trafficability. In the CLD the effect of trafficability on crop water needed is considered so for the purpose of the water management only the trafficability during spring time needs to be considered.
- While trafficability can reduce crop transpiration due to a smaller crop this does not imply that ET from a bare and possible water-logged field is negligible. The resulting ET is assumed to be a fraction ('fractionETBare') of the normal crop ET.

- In the final model we have also added two additional parameters:
    - The area of the polder which is needed to convert between discharges as found in rivers and for pumps (volume/time) and discharges that relate to areas such as ET and groundwater level changes (length/time) and vice versa. Inside the polder we consider the units of length/time while water transfer from/to outside the polder will be in volume/time
    - The specific yield which is used to calculate the amount of water that is released from a groundwater reservoir when the groundwater level changes. As groundwater is contained within a porous medium a unit volume of a ground water reservoir does not only contain water and a drop of 1 m in groundwater level will not result in a release of 1 m of water from the reservoir.

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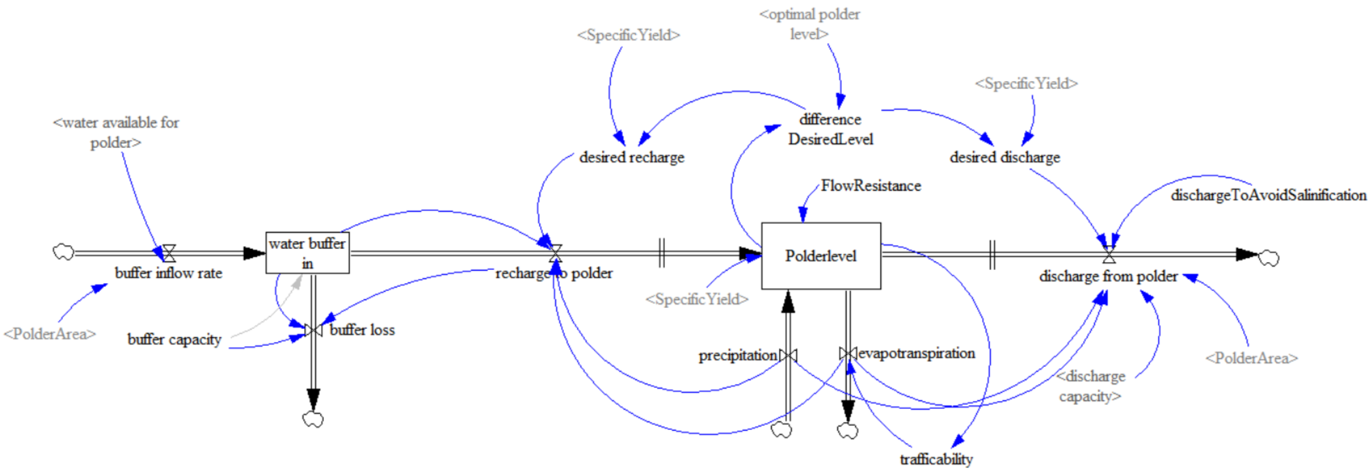


*Figure 10: SD model for the water management in the polder*

### 3.1.3.3 Quantification for the land use changes in the polder

In the polder water management model presented in 3.1.3.2 the land use fractions assigned to agriculture and nature are assumed to be independent of the water management and are read as input to the model. We now turn our attention to the upper part of the CLD which we present in Figure 11 and which is dedicated to farming and land use and how processes such as gentrification and a demand for local food production (short chain) affect these two. In this CLD we have omitted the part related to water management, only leaving a few water variables which are highlighted in green.

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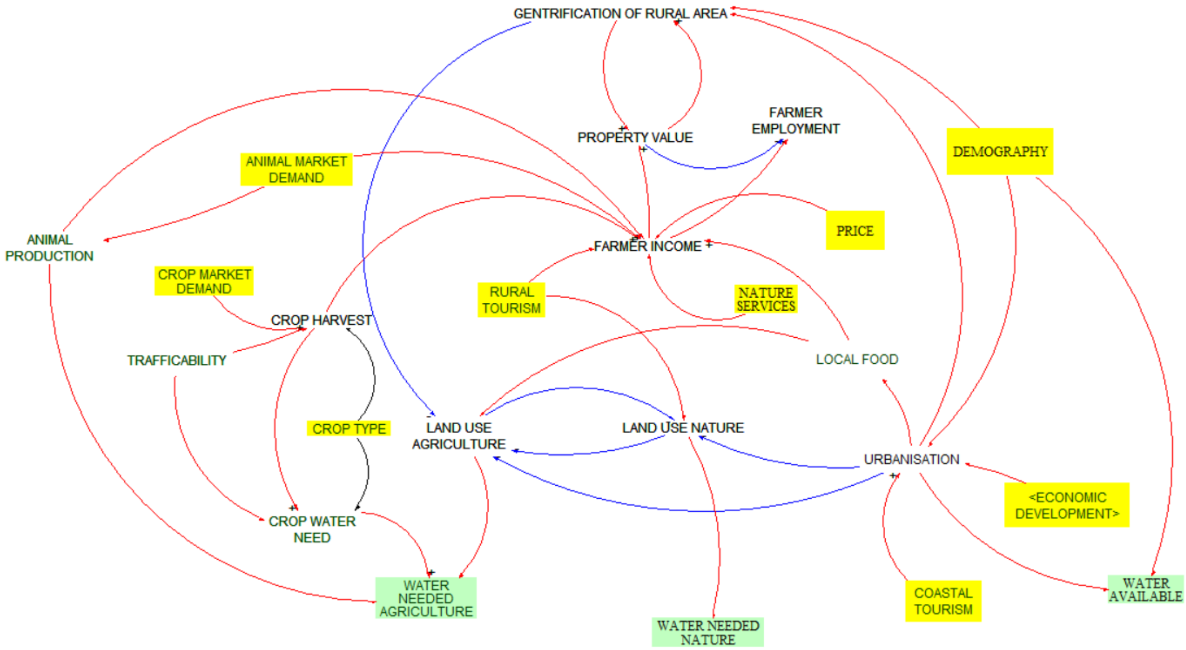


*Figure 11: Part of the CLD relating to agriculture and land use in the polder and relating this to gentrification and local food production. The variables highlighted in green are the boundaries with the water management. (inputs are yellow).*

In the CLD the value of the following variables depends on their value in previous timesteps and can be considered as stocks:

- farm property value
- land use
- the farmer employment

For the land use the CLD considers two types of land use: *agriculture* and *nature*. While not explicitly mentioned we also need to consider residential land use, a term we will use to identify the land use that is not agriculture nor nature and that results from converting either nature or agriculture area through processes such as gentrification and urbanisation. If the total area available remains constant the sum of these three land use fractions is one. This implies that if two of the three fractions are known the third can be calculated. For the model we will only explicitly consider the agriculture and natural land use. In theory all three land use types could convert to one another. To simplify the model, we assume that once land use is converted from farm or natural to residential land use it will never convert back. This also means that we assume that residential area will never convert to natural or agricultural area.

Based on the CLD we can distinguish the following flow rates for the three stocks related to farming - farm property value, farm land use and farmer employment:

- The *property value* can increase due to gentrification and the farmer income.

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- The fraction of the area assigned to agricultural land (*land use agriculture*) will decrease with gentrification and *urbanisation* and by conversion to natural area (*land use natural*). The area can only increase by conversion of natural areas. This conversion will be due to planning authorities decisions, a process that is missing in the CLD. Depending on the planning authorities a decrease (increase) in natural land area could mean that there is more (less) land available for farming. A demand for local food production (short chain, farm shops) will have a positive effect on maintaining farms and less will be sold as residential property.
- When farmers stop they sell their farm to an existing or a new farmer or sell it to be used for residential purposes (gentrification). Whether other or new farmers will buy the property will depend on how expensive the property is and how profitable it is to be a farmer. We assume that the demand for farms from the residential sector is insensitive to property value as those interested are often wealthy and price is less of an issue. Besides retirement, farmers will eventually have to stop if their farm is not profitable (= too low income) and they might be tempted to sell their farm if they can fetch a good price.
- Farmer income will depend on the *animal production* and *crop harvest* and the *price*s offered for the produce. This can be seen as the 'normal' income from operation. The net result will depend on whether operation conditions are optimal. On the CLD the *trafficability* and *water availability* for crops and animal husbandry are variables which will determine the suitability for farming. These variables are calculated in the water management part of the model and used here in the income calculation. Also revenues from direct sales to customers are mentioned (*local food*) as well as *rural tourism* these are included as an additional source of income for farmers.

Besides these flows we can also add the following which are not shown in the current CLD:

- We assume property value never decreases and there is a basic increase so that property value is in line with inflation in the long term.
- Farms can only be bought if there are farms for sale. The farm availability will also affect the property value. Farms can be bought by new farmers or by rich citizens that fancy a rural estate (gentrification). To better represent the availability of farms that are available for sale, we replace the stock 'farmer employment' by 2 stocks 'active farms' and 'farms for sale'. The model uses a monthly time step and as average sales times are likely to be in excess of 1 month this warrants adding a stock for the farms for sale. The 'farms' stock is also easier to relate to 'land use' and 'property price' than 'employment'.
- An obvious reason for which farmers stop farming is because they retire. This is the 'natural' stopping rate and depends on demography.
- Farms can also be passed on in the family which means that only a fraction between 0 and 1 of the farms belonging to farmers that retire are actually sold. In case a farm is passed on this means it is effectively never up for sale and farm availability is reduced.

The resulting SD model is shown in Figure 12.

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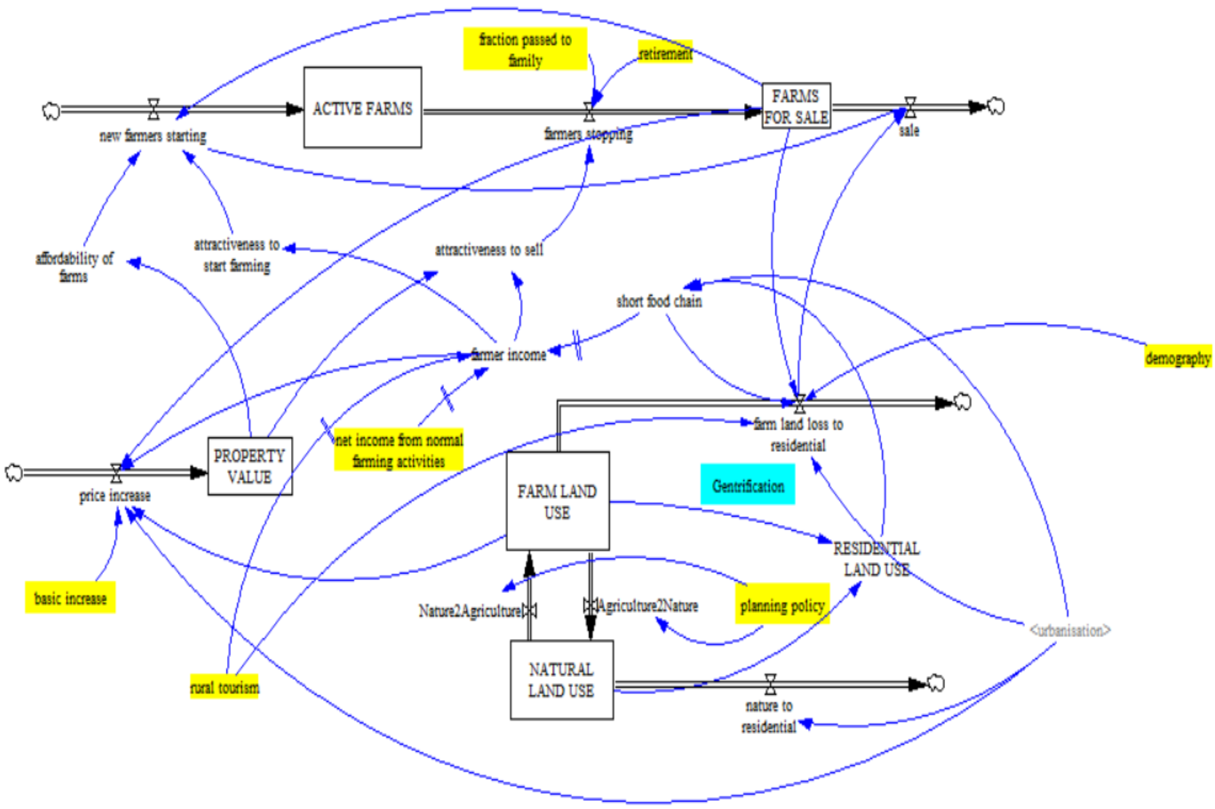


*Figure 12: SD for changes in agricultural land use due to gentrification. (inputs are yellow)*

Missing from the SD model structure as shown in Figure 12 are the initial values of the stocks. The flow rates shown in the SD model will be modulated with the stocks and different auxiliary values:

- Rate at which new farmers start will change with
  - Availability of farms as a function of farms for sale
  - Affordability of farms as a function of property value
  - Attractiveness of starting a farm as a function of farmer income
- Rate at which farmers stop is the retirement rate + an extra term dependent on
  - How attractive it is to sell the property as a function of property value and farmer income
- Rate at which the property value increases is a basic increase rate (inflation) and will change with
  - The residential land use
  - Farmer income (or profitability)
  - Availability of farms as a function of farms for sale
- Rate at which farm land is lost will change with
  - Availability of farms as a function of farms for sale
  - Rural tourism and a short food chain where customers buy products directly from farms will deter gentrification not only through the effect of higher income to the farmers
  - Urbanisation will

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Missing from the above SD model (Figure 12) are also details on the farmer income. In the CLD shown in Figure 13 we extract the part of the CLD (Figure 11 ) that relates to the income.

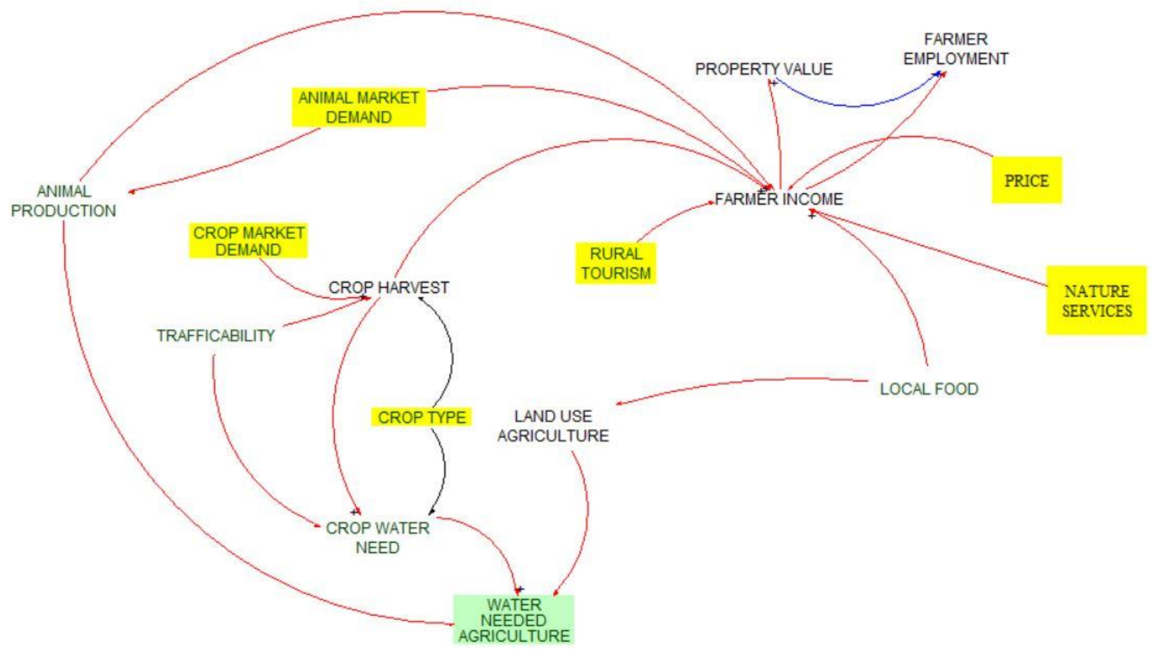


*Figure 13: Part of the CLD for the farmer income (inputs are yellow).*

According to the SD model in Figure 12 the farmer income depends on the local food sales, nature services, rural tourism, the suitability of land for farming and the net income from normal farming practices. For the latter, based on the CLD, the approach for both animal and crop production is to consider the market demand to decide on how much will be produced. By multiplying the quantities produced with a price, the income can be calculated. The costs of operation and maintenance are missing in the CLD but should be considered to calculate a net income. To remain true to the original CLD and, more important, to avoid the need for a more detailed SD model to represent the economics of farm management, we choose not to introduce the actual costs but multiply the income with a profitability factor to simplify the net income calculation. The SD model we have constructed in Figure 12 also ignores that the farmer income in a single month does not in itself determine profitability as losses in single months and even years can be compensated by profits at other times. To model the capital in the farm we therefore need to consider the income over a longer period. This can be modelled by using a stock for the capital or, alternatively, by smoothing the income which is the solution we select here. this is shown in the SD model by adding delay marks (//) to the arrows connecting the net income from normal farming activities, rural tourism and short food chain to the net income.

From the CLD the impression is that, except for the trafficability, the information flow is only one way from the agriculture sub-model to the water management sub-model. Indeed, the arrows are

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only from land use agriculture to water needed for agriculture. In reality, there will be a feedback and agriculture will be affected by water availability and salinity. In the SD model (Figure 12) we present this feedback in the variable 'suitability land for farming'. This can be further detailed in the following feedbacks:

- Salinity level: animal husbandry is a function of salinity and if water is too saline, alternative water sources might be needed
- Drought: water stress will affect crop production depending on crop type
- Trafficability: if trafficability is too low machinery can't be used on the fields and sowing or harvest are impossible

The crop area which is coupled to the land use for crop growth and the number of animals produced can be used to calculate the water needed for agriculture. This is then input to the polder water management sub-model as water needed by agriculture and is used to calculate how much water is actually available for agriculture. In Figure 14 we present the final agriculture model for calculating farmer income and feedback from the water management to the farm production.

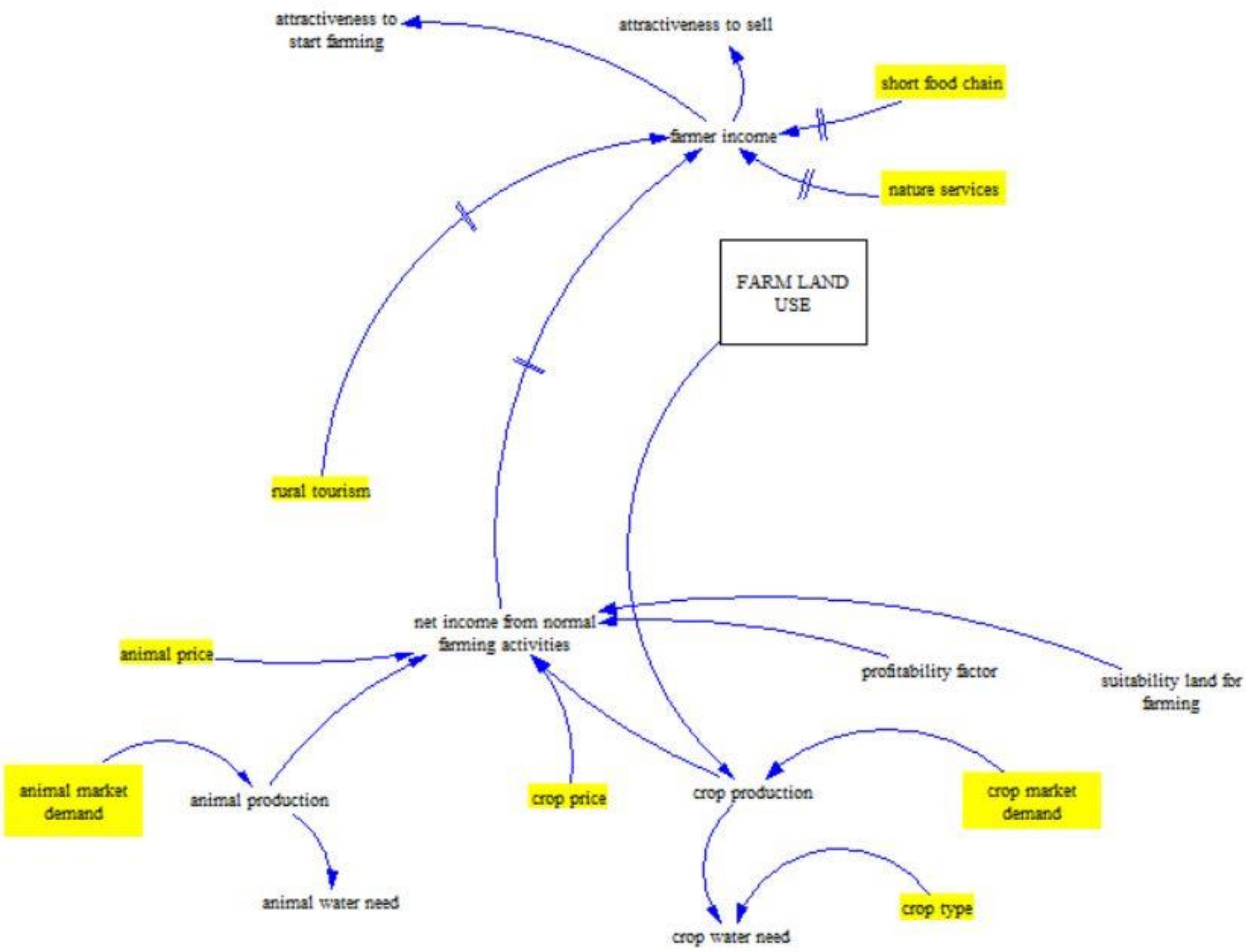


*Figure 14: Excerpt of the SD model for modelling farmer income. (inputs are yellow)*

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The scope of this sub-model was "Climate resilience: Impact of sea level rise and other effects of climate change on low lying inland farming land and nature and coastal safety". With the above modelling structures, we have covered the low lying inland farming aspect. The remaining topics are the relation with nature and coastal safety. These are highlighted in the CLD in Figure 15.

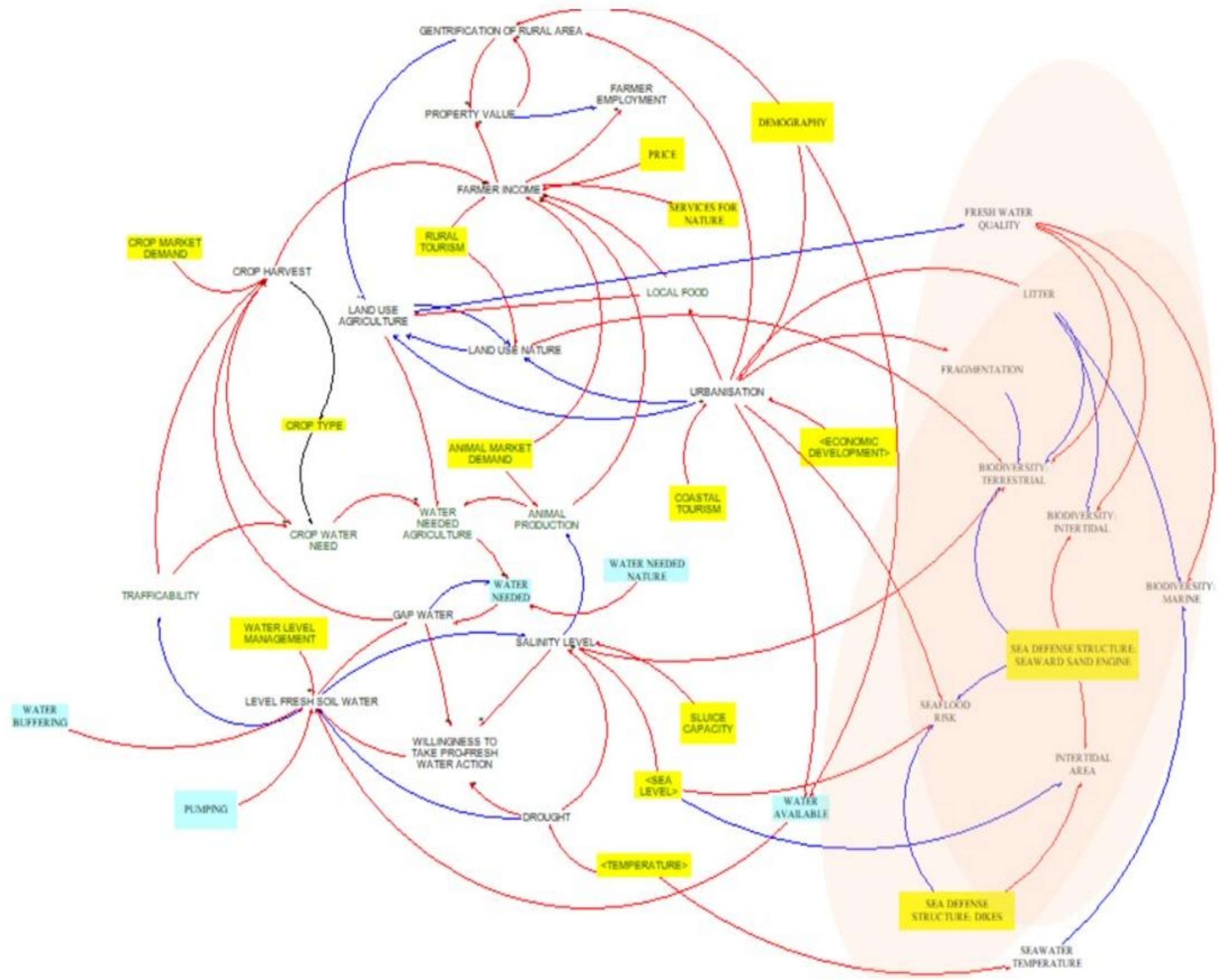


*Figure 15: Complete CLD of the water management - farming- nature- flood risk system with the nature and coastal safety aspects highlighted in orange. (inputs are yellow)*

The relevant part of the CLD in Figure 15 is repeated in Figure 16. In this the following variables are likely stocks:

- The biodiversity variables: biodiversity will improve and deteriorate gradually over time and is not just a direct or immediate result of the variables that have effect on the biodiversity.

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- Some of the inputs are stocks such as dikes and other structures to improve the coastal safety. These are inputs to the model and therefore state should be included implicitly in the time variation of these inputs.
- Urbanisation is also a stock. Until now we have assumed that it's value is directly related to other variables as demography, economic development and coastal tourism without considering previous state. We know acknowledge that the urbanisation is in fact a state variable. To simplify the model, we consider the urbanisation to be an irreversible process so that urbanisation can only increase.
- Litter and fragmentation are a consequence of urbanisation but currently there are no obvious variables that will modulate this such as spatial planning for fragmentation and strict fining of perpetrators for littering.
- Also, fresh water quality could be a stock but here we consider this an auxiliary and apply a smoothing operation to model the slow variation and delay in response.
- We assume the biodiversity can restore itself. To model this, we add natural restoration factors for the three stocks.

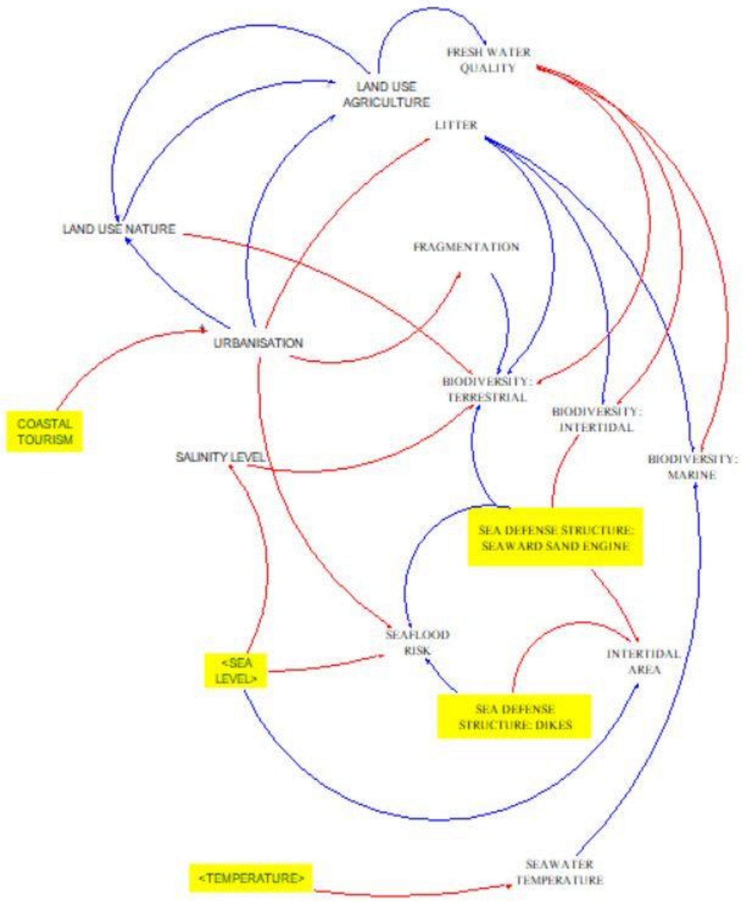


*Figure 16: Part of the CLD that relates to nature and coastal safety. (inputs are yellow)*

The resulting SD model for the CLD in Figure 16 is shown in Figure 17.

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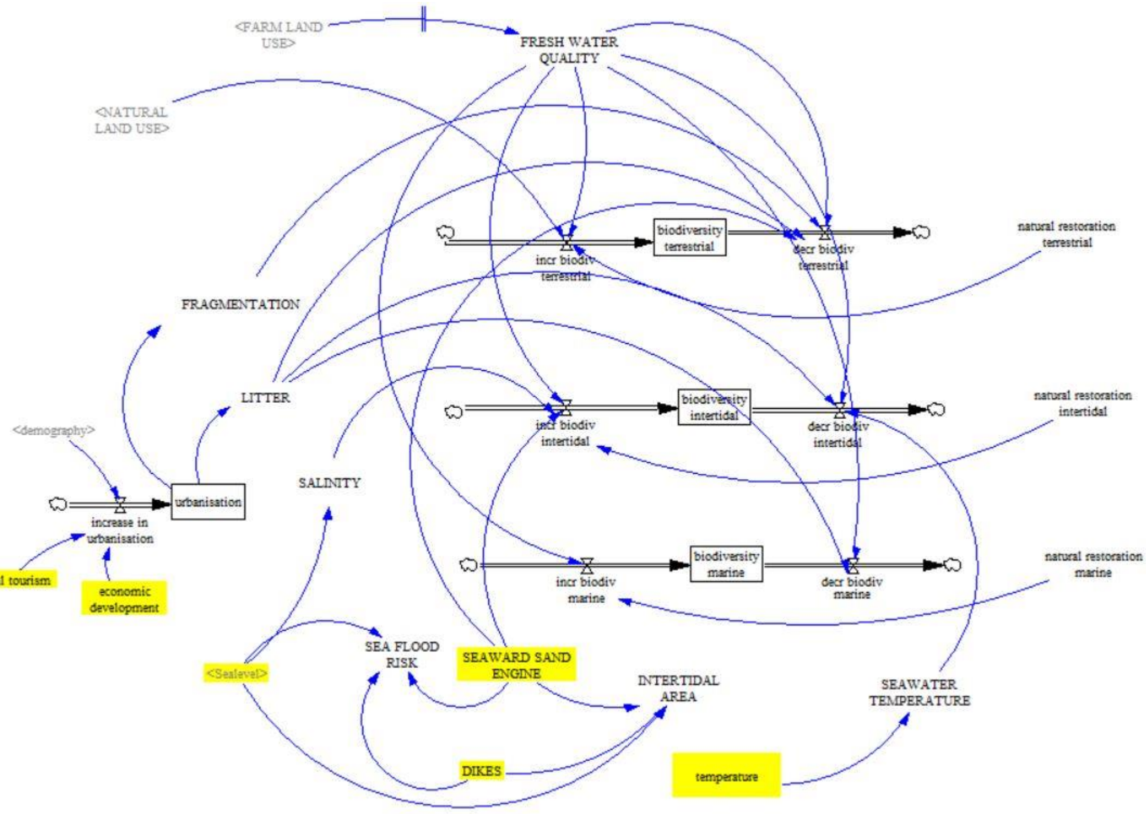


*Figure 17: SD model for nature and the coastal security. (inputs are yellow)*

### 3.1.4 Pilot model 2 design: Port and off shore activities

#### *3.1.4.1 Model scope of the port and energy sub-model*

The model scope for the second pilot model was determined together with the Port of Oostende and the provincial development agency (POM) who are involved in the development of marine and coastal industrial activity. Regardless of the limited marine space available in Belgium, Belgium has over little more than a decade managed to take on a significant role in the deployment of wind farms at sea and with 1,186MW installed capacity in 2018 had the 4$^{th}$ largest capacity in Europe after the UK, Germany and Denmark (Kruse et al., 2019). Initially, the model development for blue industry in Coastal was focused on wind farms at sea and how the production could be used for hydrogen production, desalinisation and as a complement to electricity production onshore. One of the problems modelled was the need for grid accommodation of the electricity produced by an intermittent source such as wind energy (Dijkema et al., 2009, Crabtree et al. 2010). Further discussion with energy experts (oral communication Vingerhoets, P. and Meinke-Hubeny, F.) however led to the conclusion that in the future, scenario’s where electricity surplus from wind-energy are a problem are not likely as enormous amounts of electricity will be needed to cater for the decarbonisation of our society and the enhanced interconnectivity of the grid in Europe is expected. An interesting report in this respect is a Wuppertal study that analyses the infrastructure requirements for the full decarbonisation of the chemical, steel, and cement industry in Europe by

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2050 (Wuppertal Institut,2020). Based on this insight and a discussion with the MAL actors for Blue Industry, it was decided to refocus/broaden the scope towards:

- All aspects of wind parks at sea including wind turbine (de)commissioning and the development of onshore infrastructure and know how to support these activities;
-
- In general, all aspects of off shore wind farms (deployment, maintenance and decommissioning) as well as related activities such as hydrogen production, desalinisation or recycling of decommissioned turbines are seen as a business opportunity that favours innovation and attracts investments in research and development to the area;
-
- Future expansion of blue industry could be limited by the availability of a qualified labour force and the physical limits set by space that can be used for this purpose both off shore where the wind parks are and on shore where space for port facilities and infrastructure are needed.

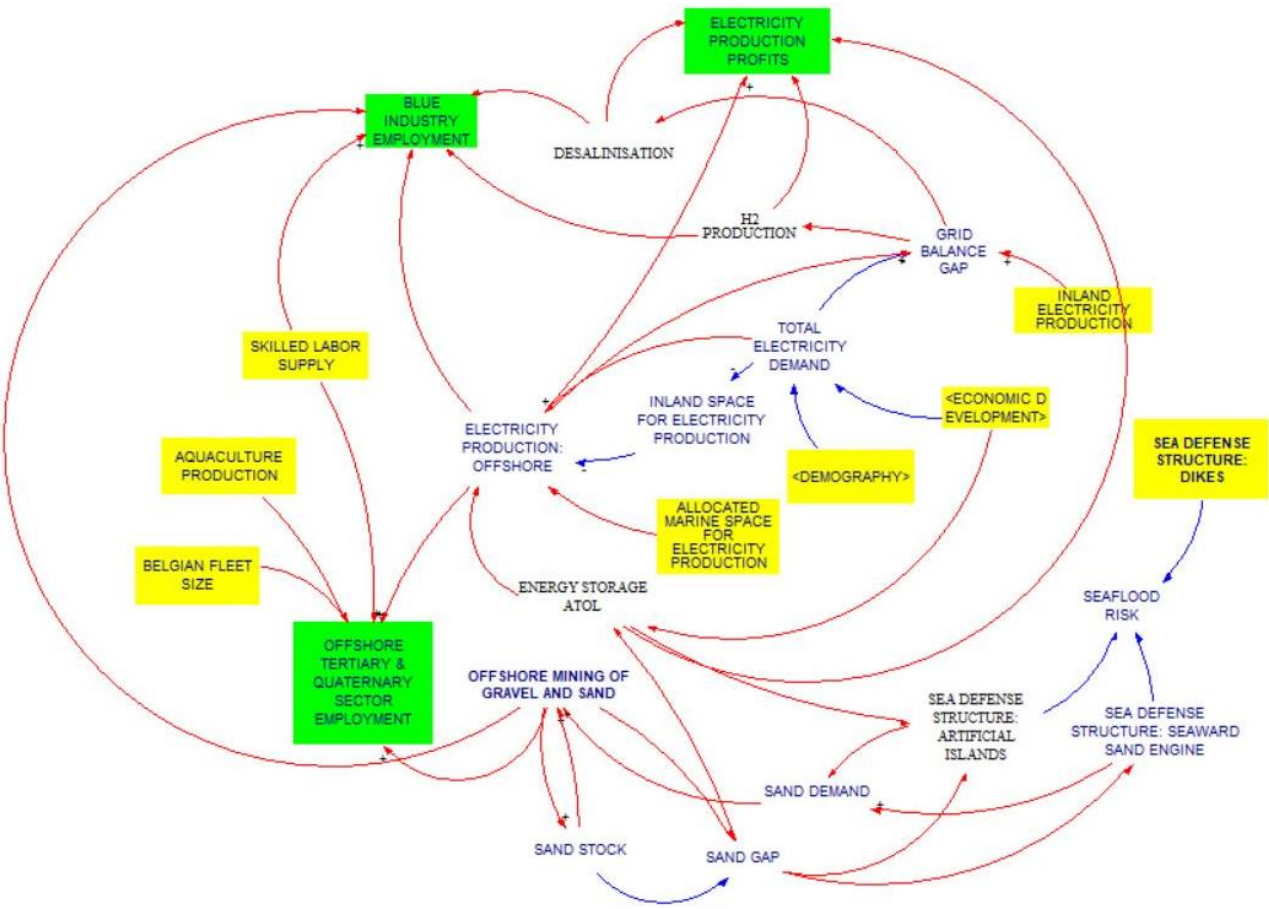


*Figure 18: CLD for the Blue Industry established from the sectoral workshop. Inputs are highlighted in yellow. Outputs that are not used elsewhere in the CLD are in green.*

In the original CLD (Figure 18) the following topics can be recognised: 1) off shore electricity production and activities linked to this, 2) employment, 3) off shore mining and 4) sea defence

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structures. Sea defines has been considered in the first sub model albeit in a somewhat simpler form but will not be further elaborated here. The sea mining is not considered further at this stage but could be added later if requested by MAL actors/stakeholders. In the current development we focus on the marine wind parks and consider the sea defence and offshore mining as an alternative use of the available marine space, space that will then not be available for further expansion of off shore wind energy.

An obvious physical limitation to deploying an off-shore wind park is available marine space. This is regulated by the marine space use map for which the most recent version for 2020-2026 is shown in Figure 1. For our purpose, as the focus is on wind parks, we will distinguish between areas suitable for renewable energy and other areas. The sum of both these area types will be the total area of the Belgian territorial zone. While the Marine Spatial Plan 2020-2026 establishes the current area available for the different functions, future revisions might enlarge the area suitable for renewable energy and thereby decrease the area available for other uses or vice-versa. The Marine Spatial Plan is revised every 6 years.

As explained in the first paragraph, for the off-shore wind electricity production, we will not focus on grid accommodation in the model. This implies that the grid balance gap in the original CLD (Figure 18) is not an issue and that the onshore demand will always be able to absorb the electricity produced by the offshore windfarms if that is necessary. This however does not preclude that produced electricity could be stored (battery, energy atoll), used to produce hydrogen or for de-salinification of sea water but this is not required because of surplus electricity being produced that can't be used by an onshore user. This significantly simplifies the CLD as shown in Figure 18 as there is no feedback from electricity demand/consumption to electricity allocation to the different possible uses.

While the decommissioning is explicitly mentioned by the MAL actors this is currently not considered in the CLD. The CLD is therefore extended with processes related to the decommissioning:

- While only decommissioning is mentioned this can also be extended to include other phases in the life cycle of the marine wind park. Once marine space is released it again can be used for other purposes of which the installation of a new wind park seems a likely option. This implies that marine space will be possibly occupied by a sequence of wind parks where the request for a new concession and plans for a new wind park (by possibly new candidates) will go hand in hand with plans for decommissioning by the owners of existing wind parks. In our CLD we will distinguish planned, operational and end-of-life marine wind parks.
- In general, decommissioning is required by the end of the 20-year turbine service life. So far, in the offshore wind sector only a few wind turbines have been dismantled offshore in Europe and experience with the decommissioning is still limited but in the near future this will change as from 2020 to 2030, 1,800 offshore wind turbines in Europe will reach their end-of-life (Topham et al. 2019). Upon reaching their end-of-life there are a number of

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options for the wind turbines: lifetime extension, repowering or decommissioning where decommissioning can be either a partial or a total removal of the offshore wind foundations. In the permit granted for the wind park, the site's restoration to its original condition is required. However, the permit also considers the need for consultation concerning the practical implementation of this requirement and how far this can go. While there is to date limited experience with the decommissioning of marine wind parks, experience with oil rigs indicates that biological production and biodiversity are enhanced due to the presence of the decommissioned structures (Frumkes, 2002; Sayer and Baine,2002). While partial removal is cheaper at time of decommissioning it also incurs extra costs due to the requirement for subsequent monitoring of the site.

- Repowering as defined here includes two types of actions. Full repowering refers to the complete dismantling and replacement of turbine equipment at an existing project site. Partial repowering is defined as installing a new drivetrain and rotor on an existing tower and foundation and allows extending the wind park lifetime to two generations (Sun et al., 2019). Partial repowering – for example by replacement of only the turbine drivetrain and rotor—allows existing wind power projects to be updated with equipment that increases energy production, reduces machine loads, increases grid service capabilities, and improves project reliability at lower cost and with reduced permitting barriers relative to full repowering and greenfield projects.

According to the German Federal Ministry for Economic Affairs and Energy (BMWI, 2015) offshore wind energy offers significant economic development potential. Whether during the construction of plant components, the assembly of a wind farm or its subsequent operation – generating energy from the sea requires products and expertise from numerous industries. The fledgling technology is also in need of specialised professionals. The BMWI report (2015) mentions following elements in the value creation chain in off shore wind energy:

- Project planning and development
- Financing and insurance
- Turbine construction
- Transport and assembly for turbines and wind parks
- Grid connection
- Operation and maintenance
- Disassembly and/or repowering

Each of these elements requires specialised labour and facilities most of which will have to be stationed at or near the coast. In Belgium, the existing and rising economic relevance of the offshore wind energy business is expected to result in about 16,000 jobs between 2010 and 2030 being created (Belgian Offshore Platform 2019). The European Union anticipates 170,000 jobs in the industry by 2020 and around 300,000 just a decade later (BMWI, 2015). Profiles that will be needed range from technical profiles such as engineers and skilled workers from the metal and electrical

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industries, surface engineering and mechatronics, meteorologists, geologists and marine biologists, skippers and machine operators industrial climbers and divers but also commercial experts who can assess the economic viability of future wind farms and experts in financing and insurance and in the areas of approval and certification In Belgium, 39 per cent of the interviewed stakeholders expect labour market and access to qualified employees to become a problem in the future (Kruse et al., 2020).

When it comes to facilities, the mere size of many of the components involved poses logistical challenges (BMWI, 2015). For example, motorway bridges with a standard height of 4.5 metres are insufficient for the transportation of the six-metre-wide rotor blades. To support the off-shore wind farm industry ports can provide facilities for (BMWI, 2015) preassembly during deployment or the import and export of the installation for both of which sufficient storage space, quay surfaces with heavy-duty capacity and loading capacities are essential. Ports can also be safe havens in bad weather, for the ships used in wind farm construction. For maintenance and operation (M&O) of the wind park, the port can take on a service function offering response, supply and research, development testing and training. For the decommissioning, one of the 4 main concerns of Belgian Stake holders (Kruse et al., 2020) is the large storage space requirements to store the decommissioned parts of turbines before having them sent to other locations. Almost half of them (44%) believe new facilities will be required for waste management and recycling.

Finally, from the Decom Tools project stakeholder analysis (Kruse et al., 2020) it became apparent that the main concern of the Belgian stakeholders in the Decom Tools project is the high degree of uncertainty related to permits related to offshore wind and decommissioning. All investments, new machines or new techniques depend on permits and regulatory decisions on what is going to happen to the physical location of wind farms after decommissioning. Without having these in place, companies struggle to make a business case to move forward

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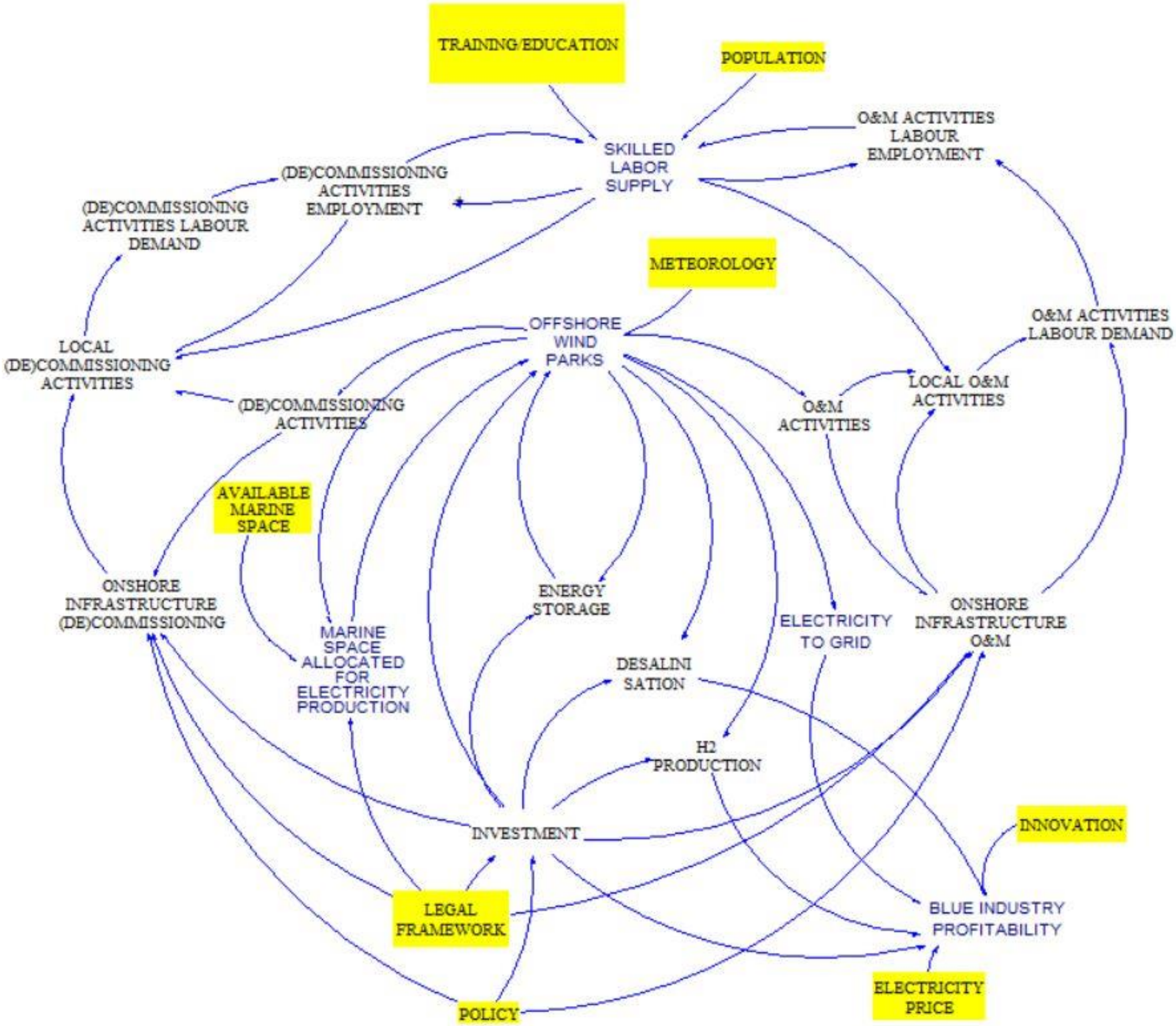


*Figure 19: Adapted CLD with focus on the activities accompanying wind parks at sea, infrastructure and labour force requirements. (inputs are yellow)*

#### 3.1.4.2 Quantification of the port and energy sub-model

The following elements need to be addresses in the SD model:

- the off-shore wind park electricity generation depending on the characteristics of the turbines and their mutual spatial configuration;
- In the CLD the temporal relations are missing and thus the different steps in the lifecycle of the wind turbines. For the SD model we will distinguish both the pre-operational steps starting with planning through construction and deployment, the operation and maintenance phase (O&M) and the end-of-life where the turbines need to have their lifetime extended, to be repowered or decommissioned.

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- Wind parks require space (marine spatial planning), infrastructure and a skilled labour force. While the latter two don't necessarily need to be sourced locally in Belgium and are sometimes not even locally available currently, the development of marine wind parks and associated activities will entail a demand for such infrastructure and labour force which represents an opportunity for Belgian industry.
- Investors and project developers in the end are, if not only, mainly interested in the profitability of the offshore marine wind parks. As an add-on to the SD model we should therefore assess the profitability of the sector.
- All aspects of the offshore wind energy industry favour innovation and attract investments in research and development to the area.
- Legislation and clarity in permits and procedures for all aspects related to the deployment, operation and decommissioning or repowering of off shore windfarms. Especially for the end-of-life options there is a lack of step-by-step explanations and procedures on what to do to obtain the permits for lifetime extensions or what will happen to the wind farm site after decommissioning (Kruse et al., 2020).

The legal and policy aspects are currently the aspects that are least clear and will be modelled as input (drivers) that can either promote or demote the other activities. As drivers we are assuming that there is no feedback from the wind park operation. In reality, offshore wind park profitability and employment could have a long-term effect on policy and also legislation. Effects on the marine environment are not included here as we assume a neutral effect as reported by Degraer et al. (2013).

### The wind parks

To calculate the energy produced by the wind turbine we multiply the wind park nominal capacity CapNom by a capacity factor[3]. The effect of the uneven distribution of available wind energy with months and the effect of changes in yearly available wind energy due to climate change will be accounted for through a monthly ($f_m$) and a yearly ($f_y$)factor:

- $E(y,m) = CapNom * CapFact * f_m * f_y$

Where:

| | |
|---|---|
| y: year considered | [-] |
| m: month considered | [-] |
| E(y,m) : energy produced in year,y and month,m | [MWh] |
| CapNom: Nominal listed capacity of the wind parks in | [MWh] |
| CapFact(y): capacity factor | [-] |
| $f_m$: effect of uneven distribution of wind energy over months | [-] |
| $f_y$: effect of uneven distribution of wind energy over years | [-] |

While the CLD (Figure 19) considers planned, operational and decommissioned wind farms, for the SD model we consider the stocks that in the end will be needed for the result and consider the energy capacity and the area occupied by the wind farms. For both these, we consider the following stocks for the offshore wind parks: planned, operational first generation , end-of-life and an operational second generation. The end-of-life stocks can be either decommissioned (a flow) or partially be

[3] https://en.wikipedia.org/wiki/Capacity_factor

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repowered (a flow) to become a second-generation operational stock. For the wind park capacity, the corresponding SD model structure is shown in Figure 20. The stock represents the installed effective capacity of the wind parks in MWh based on the  nominal capacities multiplied by their respective capacity factor for respectively all planned, operational or end-of-life wind parks.

To assure the correct dynamics considering the expected lifetime of both the first and second generation of the offshore wind farm we, delay the rate used for increasing the stock by the lifetime to calculate the outflow using a fixed delay. This ensures that the capacity added for the windfarm in timestep, t is removed in timestep, t+ lifetime.

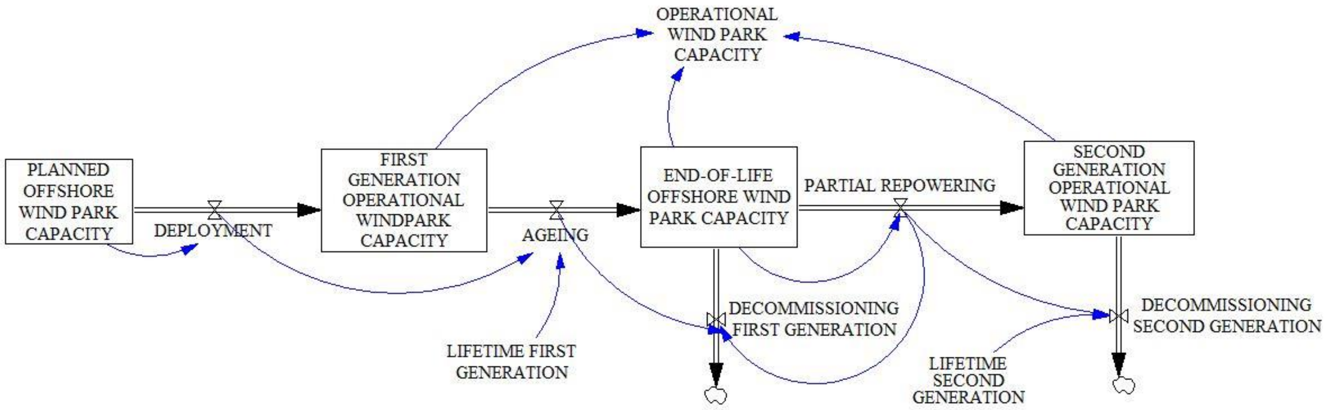


*Figure 20: Different offshore windpark capacity stocks.*

As can be expected, the structure for the wind park area stock is very similar and shares the flow rates with the energy capacity model (Figure 21).  As can be seen in Figure 21, instead of calculating the stock for the planned capacity and area we read these as inputs to the model. This assumes that these are not affected by other variables in the model and is clearly a simplification as profitability will obviously affect the plans of investors. For now, we adopt this simplification as it will facilitate testing and provides for interesting options for scenarios.

Up to now the model developed merely calculates the energy capacity of the wind parks at sea. To transform this into actual electricity produced, the capacity  will need to be multiplied by the factors $f_m$ and $f_y$ to account for the variations  in wind energy between the months  ($f_m$) and the years ($f_y$) considered in the simulation. The effect of climate change, represented by the "meteo" variable in the model,  can be accounted for by modifying the month and year factor. The produced electricity can be assigned to the grid or, alternatively, be used for producing hydrogen or for desalinification. Both options are considered in the model by calculating the equivalent amount of hydrogen  and fresh water that can be produced from the produced electricity assuming a user defined capacity and distribution of produced electricity for both processes. Excess electricity produced  is assigned to the grid. The resulting SD-model is shown in . The reader will notice that the energy storage is missing from this model. The effect of storage is to displace capacity in time. With a time step of 1 month storage effects at a smaller time scale will probably cancel out while if there are effects over months these could be accounted for through the monthly time factor $f_m$ that is currently used to model the effects of differences in wind energy for the months of the year.

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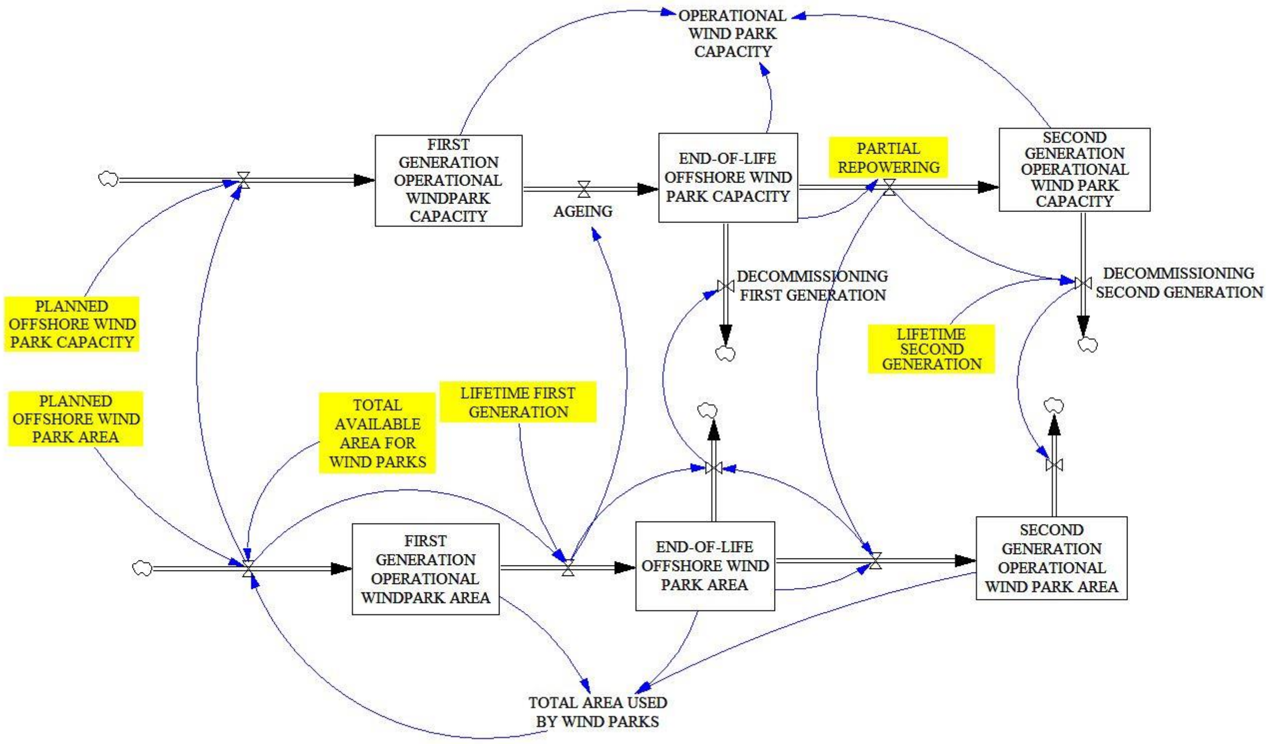


*Figure 21: Offshore wind parks capacity and area. (inputs are yellow)*

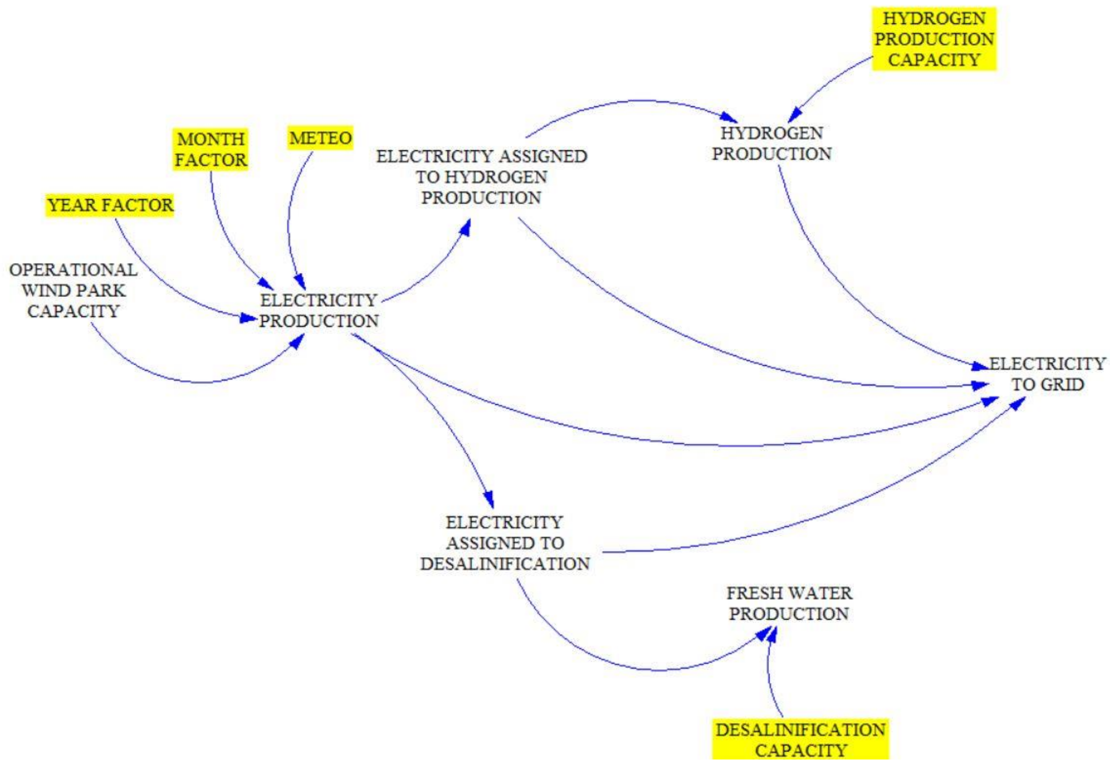


*Figure 22: Electricity production from wind park capacity and assignment to the grid, hydrogen production and de-salinification. (inputs are yellow)*

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The different aspects of marine wind park deployment, operation and maintenance (O&M) and decommissioning require a number of services and activities. Some of these activities relate to the (de) commissioning while others are necessary for O&M. We distinguish between these two types of activities as they relate to different phases in the life cycle of the wind park and are also different in terms of e.g. duration and frequency. In the SD model we therefore consider stocks for each of these two types of local activities. In our model we want to explore the possibility of local development of the required (de)commissioning and O&M activities. The demand for an activity depends on the wind park stock: the more wind parks the more wind parks will need to be decommissioned or the more need for operation and maintenance. The required activities could be sourced from existing foreign providers. For some specialised services that are not needed on a regular basis this could well be the most likely option. However, if local entrepreneurs see a market and can provide the service at more interesting conditions, the need for the activity will result in a certain local need for such an activity. The driving force for increase or decrease of the local activity stock will depend on the difference between the stock value and the local need for the activity. The resulting SD model structure is shown in Figure 23. The wind park area stocks have been omitted from this structure for reasons of clarity.

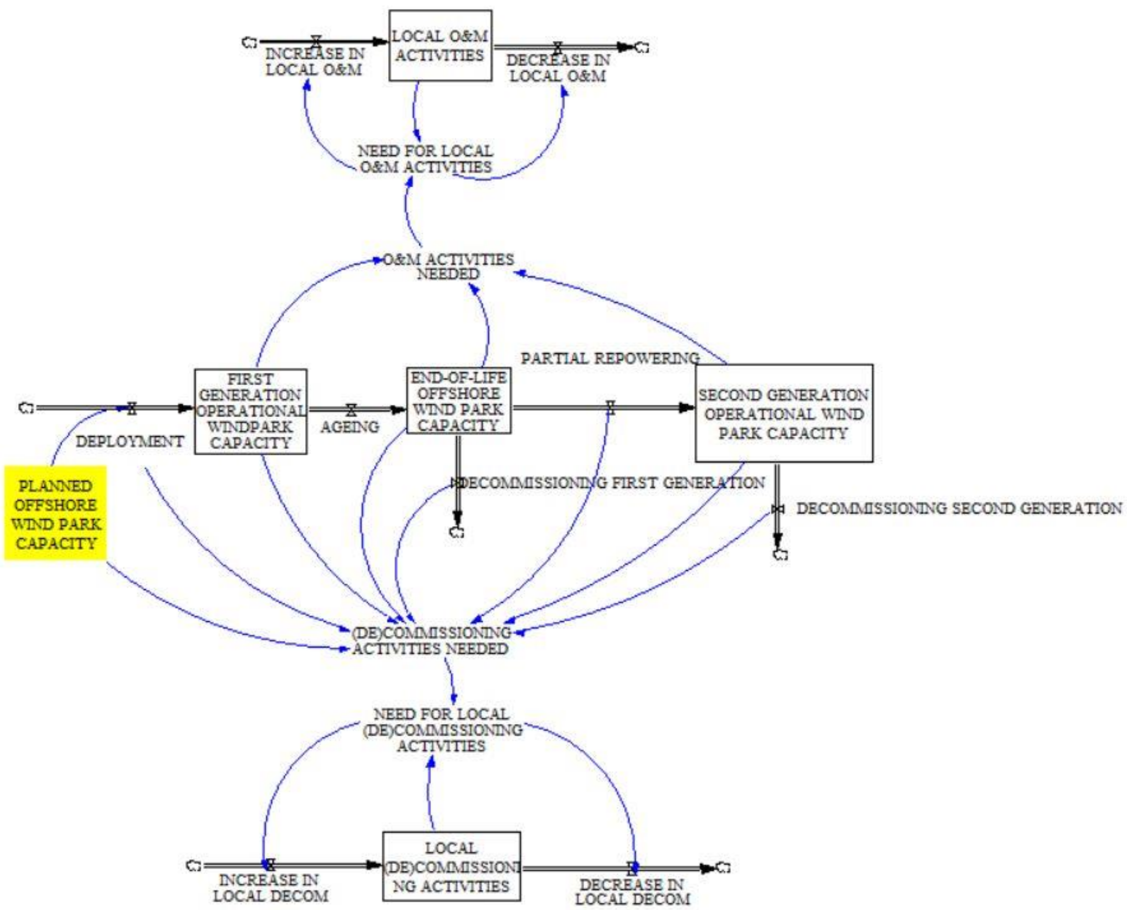


*Figure 23: Activities related to the offshore windparks: (de) commissioning and operation and maintenance (O&M) and their relation to offshore wind parks. (inputs are yellow)*

In a next step we add the structures needed for the skilled labour and infrastructure. The wind park employment stock will depend on the local activity stocks and available skilled labour stock. Much in the same way as demand for activities depends on the wind mill parks, demand for skilled labour will depend on the size of the activity stocks. The actual wind park employment will depend on the

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difference between labour required and the wind park employment stock and the increase to the required value is limited by the stock of skilled labour available. Obviously, if there is no skilled labour available, the employment in the local activities related to wind parks can't increase. The available skilled labour stock can increase if employees lose their jobs in the local offshore wind parks' industry or because new trainees become available. The stock decreases when people are hired by either the wind parks, by other sectors that compete for skilled labour or when they retire. The wind park employment stock will determine if further expansion of local activities is possible. The rationale for the infrastructure is analogous with the difference that only an increase in infrastructure is assumed. The dynamics of the increase in infrastructure is based on a difference between the actual local infrastructure stock and the local stock needed for the local activity (= demand for local infrastructure). As long as more local infrastructure is needed, this will increase. The local infrastructure stock will determine to what extend the local activity can increase and this feedback effectively limits the size of the stock. The resulting SD model structure is shown in Figure 24 . Notice that the wind park capacity stocks have been lumped into a single wind park capacity stock to simplify the presentation.

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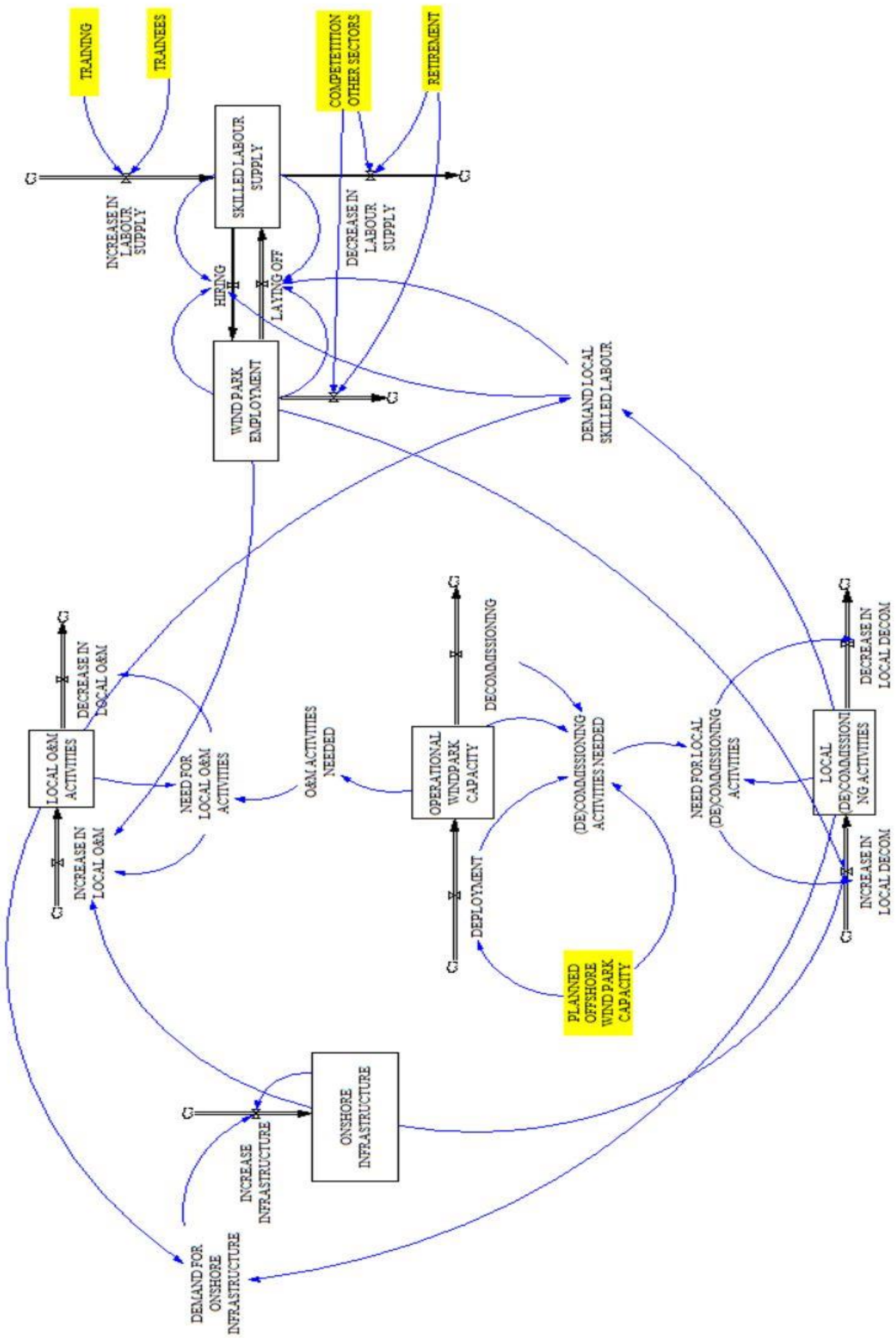


*Figure 24: SD model extended with employment and infrastructure. (inputs are yellow)*

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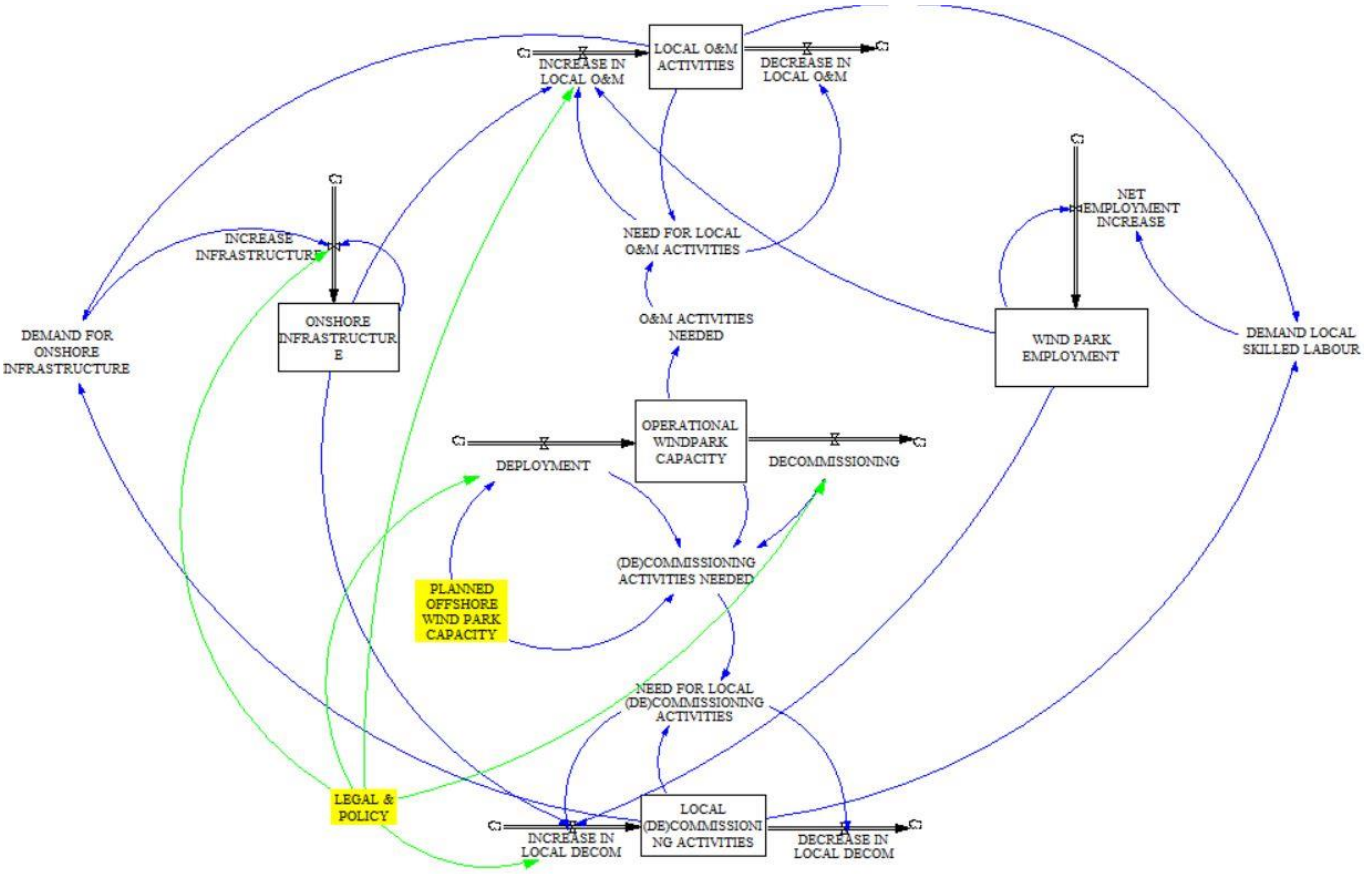


*Figure 25: SD model extended with legislation and policy drivers. (inputs are yellow)*

The SD model structure is extended with the effects of legislation and policy drivers (inputs) by considering the effect these have on the (de) commissioning of the wind parks and the development of local business activities both directly and indirectly by supporting local infrastructure development (Figure 25).

Profitability is considered in the SD model by considering the costs (investment, O&M costs, (de) commissioning costs) and benefits (income from electricity production). Depending on who is the beneficiary the assessment can be different. For the investor the profitability will be the difference between all costs and the income. For the local economy, an assessment of the profitability will also need to consider how much of the total O&M and (de) commissioning costs are due to local activities that result in local employment and profits.

The innovation is also considered as a driver and will mainly affect the profitability by lowering the costs and increasing the electricity generation. We also consider the innovation from a local perspective where innovation will increase the attractivity of the local activity so that the demand for the local activity is higher with an increase of innovation.

The resulting SD-model structure is shown in Figure 26.

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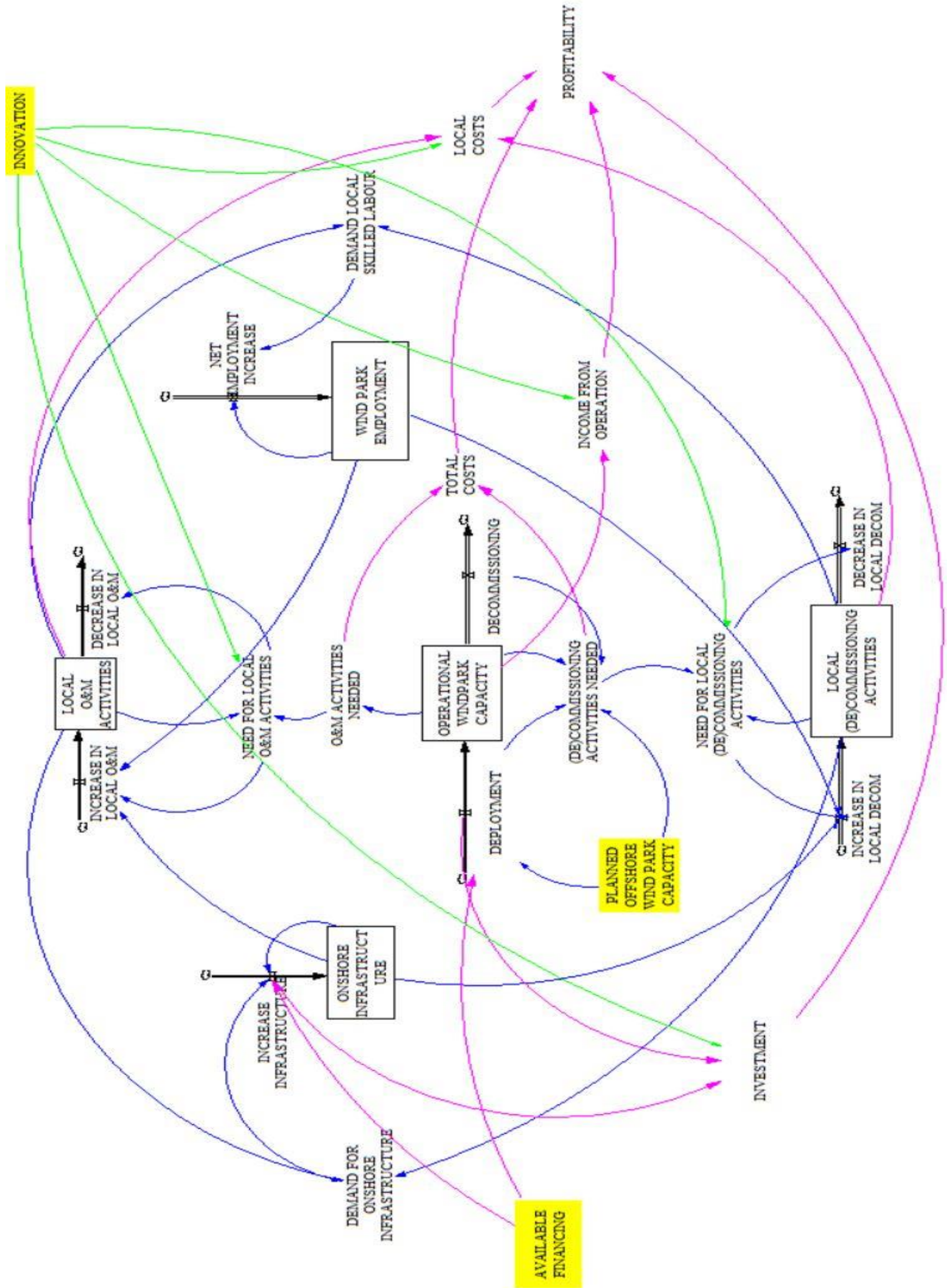


*Figure 26: SD model extended with profitability (pink arrows) and innovation (green arrows). (inputs are yellow)*

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### 3.1.5 Overview of the stock-flow models and land sea interactions

In Figure 27 the overview SD model for the climate resilience-water management- agriculture–environmental quality coastal safety is shown. The presented structure is a simplification of the full SD model derived in the previous chapters and only contains the main stocks, flows and auxiliary variables of the full system:

- Polder water system with a polder level to represent the groundwater state in the polder and in -and outflows that increase or decrease the groundwater level in accordance with the water management system;
- The spatial planning in the polder where agriculture and nature compete for space. Urbanisation is resulting in farms being bought by wealthy citizens (gentrification) and a demand for alternative food production (short food chain, ,Community Supported Agriculture).
- Farming and urbanisation have an effect on the state of the environment (water quality, litter, fragmentation);
- Climate change will have consequences for the sea level and the water balance of the polder.

In the model presented for the blue Industry Figure 28 we consider the relationship between the development of marine wind parks and available resources such as marine space, port infrastructure and services related to the lifecycle of the offshore wind parks: planning, construction, operation, maintenance, repair and decommissioning. The overview model presented in is a simplification of the different components discussed but presents the main problems that can be addressed with the model:

- The development of marine wind park industry in Belgium accounting for availability of marine space, infrastructure and skilled labour;
- An assessment of the evolution of the profitability of such activities;
- The effects of the legal framework, financing, policy and innovation on the dynamics of the development of offshore wind parks.

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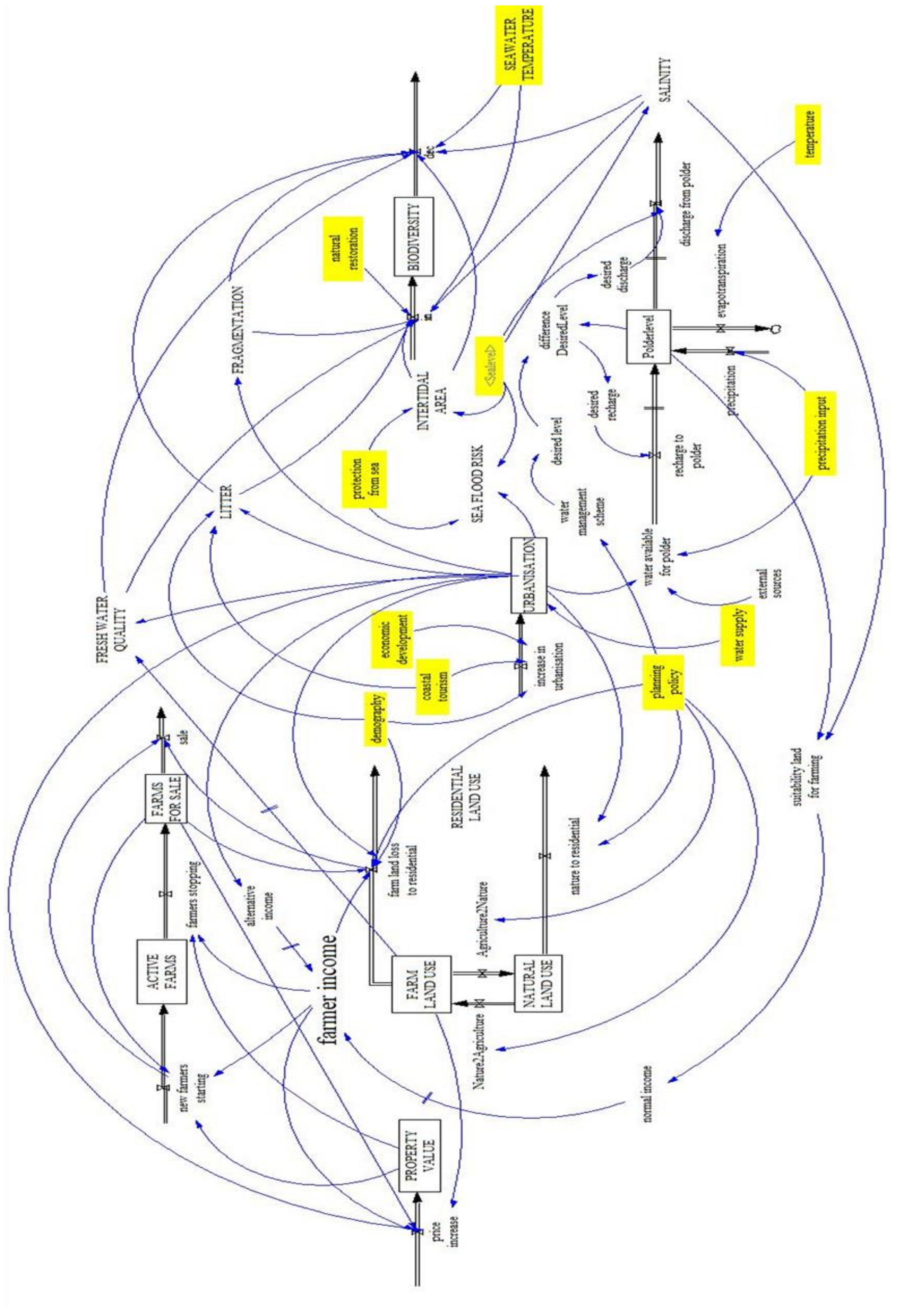


*Figure 27: Overview SD model for the polder including water management, agriculture, biodiversity and coastal safety. (inputs are yellow)*

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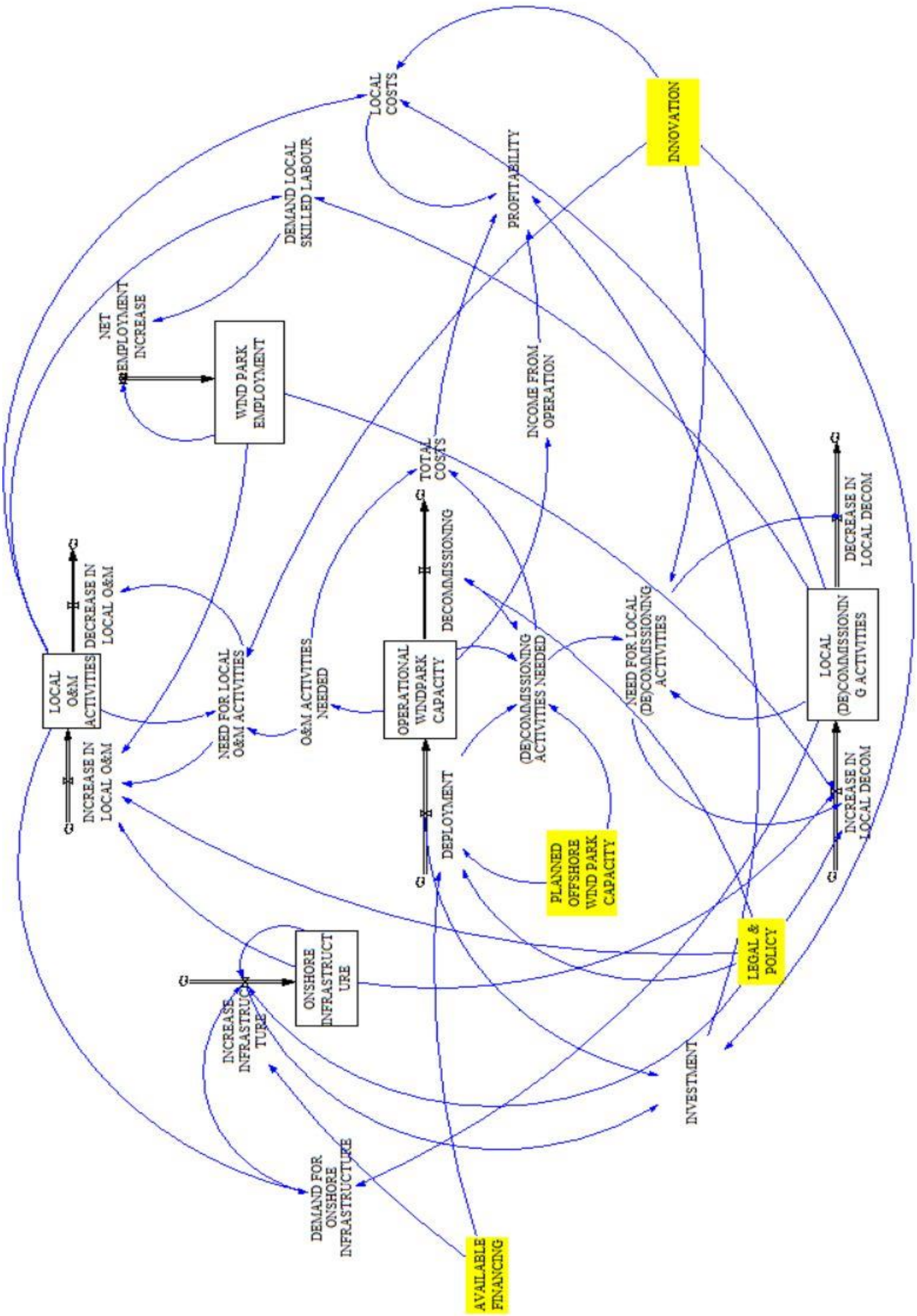


*Figure 28: Overview SD model for the blue industry. (inputs are yellow)*

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### 3.1.6 Problems that can be addressed with the SD models

Using the above SD models, the following problems can be addressed:

*With respect to the water management and land use in the polder*

- Changes in the polder water balance due to land use (farmland or nature) but also climate change and vice versa the land use that is feasible given climate change
- How much water is available for recharge to the polder considering that water available from the canal can change due to changes in sea level which will require a higher discharge from the canal and the use of canal water for the production of drinking water?
- What is the effect of using water from a waste water treatment plant and/or water recovered from sealed areas as a water supply for the polder.
- What is the effect of different polder water level management schemes? What would be the effect of changing the drain layout and thus how fast re/discharge affects the polder level?
- How will sea level rise affect the capacity for discharging water from the polder? How much pumping capacity is required to remove the water?
- How will changes in population and tourism affect the water management in the polder?
- Will it help to buffer water to bridge periods where there is not enough water and if we buffer how big does the buffer have to be?
- How can water management decisions affect the land use (agriculture/nature/residential)
- Under what circumstance is farming in the polder still profitable?
- How will farming in the polder evolve and to what extend will it still exist due to gentrification?

*With respect to the blue industry and its requirements in terms of infrastructure, space and labour force*

- Which bottlenecks are to be expected for the blue industry and when will these occur under different possibilities for development? The model considers limitations in marine space, financing and permitting.
- How will the different options in the lifecycle of a wind park affect the dynamics?
- How will future profitability of off-shore wind parks be affected by the different choices in terms of electricity use (hydrogen, …) , decommissioning options, available marine space?
- How will the availability of onshore infrastructure and local skilled labour affect the development?
- How can innovation and the legal/policy framework in which investors and operators have to thrive affect the development of wind parks?

The model can help with the following actions of the green deal:

- The polder model can help assess the impact of climate change on the water availability in the polder and how we can counteract unwanted changes. This relates to the "New EU Strategy on Adaptation to Climate Change" action
- The Blue industry model can be used for the "strategy on offshore wind" in Belgium.

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### 3.1.7 Main model variables

*Table 1: Main variables in the MAL01 SD model for water and land use in the polder. ( S: stock, F: flow, A: auxiliary)*

| Name | Unit | SD | Definition |
|---|---|---|---|
| **Polder Level** | m | S | The ground water level for the polder |
| **Buffer** | m | S | Water buffering capacity for water supplied to the polder |
| **recharge to polder** | m3/month | F | Actual water flow to the polder area |
| **discharge from polder** | m3/month | F | Actual water flow from the polder area |
| **Specific Yield** | m/m | A | The amount of water released with change in groundwater level |
| **FlowResistance** | month | A | Hydraulic resistance to exchange between the groundwater and the ditches in the polder; dependent on topology of the ditches and soil characteristics |
| **Desired Level** | m | A | Optimal groundwater level according to the water management scheme |
| **Precipitation** | m/month | A | Natural surface recharge to the polder area |
| **Evapotranspiration** | m/month | A | Natural surface discharge from the polder area due to crop water uptake and evaporation |
| **Sealevel** | m | A | Average monthly sea level |
| **Salinity** | $kg/m^3$ | A | Salt concentration in ground water. |
| **Biodiversity** | - | S | Biodiversity indicator: marine, coastal or terrestrial |
| **Urbanisation** | - | S | Indicator ( degree of urbanisation) |
| **Active farms** | #farm | S | Farms actively being used for agriculture |
| **Farm for sale** | #farm | S | Farms available for sale |
| **Property value** | Euro | S | Average price of a farm |
| **Demography (farm)** | #people | A | Non-farmer population in the area |
| **Farm land use** | ha or - | S | (fraction) Area used for farming |
| **Natural land use** | ha or - | S | (fraction ) Area not used for farming, residential, recreational or industrial purposes |
| **Residential land use** | ha or - | A | Stock derived from farm and natural land use (fraction or area) |
| **Short food chain** | - | A | Increase in farmer income due to direct, local sale of produce on the farm |

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*Table 2: Main variables in the MAL01 SD model for the blue industry.*
*( S: stock, F: flow, A: auxiliary)*

| Name | Unit | SD | Definition |
|---|---|---|---|
| **Planned offshore wind park capacity** | MWh | A | Planned annual capacity (= nominal capacity * capacity factor) |
| **Planned offshore wind park area** | $km^2$ | A | Area that will be taken by the planned off shore wind parks |
| **First generation operational wind park** | MWh or $km^2$ | S | Capacity or area of the operational wind parks that resulted from green field development or complete repowering |
| **Second generation operational wind park** | MWh or $km^2$ | S | Capacity or area of the operational wind parks that resulted from partial repowering of existing wind parks |
| **End-of-life offshore wind park** | MWh or $km^2$ | S | Capacity or area of the first-generation wind parks that need to be decommissioned or repowered |
| **Local O&M activities** | Eur | S | Turnover of local enterprises involved in the operation and maintenance (O&M) of offshore wind farms |
| **Local (de)commis-sioning activities** | Eur | S | Turnover of local enterprises involved in the (de)commissioning (O&M) of offshore wind farms |
| **Wind park employment** | #people | S | Number of employees employed in the local off shore wind industry. |
| **Skilled labour supply** | #people | S | Number of employees available and suitable for recruitment by the local off shore wind industry |
| **Onshore infrastructure** | ? | S | Infrastructure (port, quay, storage, waste processing facilities) available for the offshore wind industry |

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### 3.1.8 Data sources

Ampe, A (2007) Is golfenergie voordeliger dan windenergie? Onderzoek naar een economische exploitatie van het energiepotentieel in de Noordzee. Scriptie burgerlijk ingenieur bouwkunde. Universiteit Gent.

Bekkenbestuur (2010) Handleiding voor de opmaak van peilbesluiten in de kustpolders. (https://www.integraalwaterbeleid.be/nl/bekkens/bekken-brugse-polders/gebiedsgerichte-werking/handleiding-peilbesluiten/Handleiding%20peilafspraken.pdf/view)

Belgian Offshore Platform (2019): FAQ – Economy. [Online]. Available at: https://www.belgianoffshoreplatform.be/en/faq/. [Accessed July 2nd, 2020].

Crabtree, G., Misewich, J. et al. (2010) Integrating Renewable Electricity on the Grid A Report by the APS Panel on Public Affairs. American Physical Society (APS), Washington D.C., USA, 202-662-8700.

De Maesschalck , P., Weekers, K. (2020) De economische betekenis van toerisme in Vlaanderen Resultaten van de Vlaamse en Brussels satellietrekening toerisme 2018 Statistiek Vlaanderen Havenlaan 88, 1000 Brussel D/2020/3241/064

Debrie, E. (2017) Een grondige statistische studie van het Belgische kustklimaat Master Thesis mathematics Gent University.

Degraer, S., Brabant, R., Rumes, B., (Eds.) (2013) Environmental impacts of offshore wind farms in the Belgian

part of the North Sea: Learning from the past to optimise future monitoring programmes. Royal Belgian Institute of Natural Sciences, Operational Directorate Natural Environment, Marine Ecology and Management Section. 239 pp.

Depraetere, H and Lammertyn, K (2008) Getijdenenergie: een toekomst vanuit Belgisch perspectief? Onderzoek naar de technische en economische haalbaarheid. Scriptie burgerlijk ingenieur bouwkunde Universiteit Gent

Dijkema, G., Lukszo, Z., Verkooijen, A., de Vries, L., Weijnen, M. (2009) De regelbaarheid van elektriciteitscentrales Een quickscan in opdracht van het Ministerie van Economische Zaken 22 p.

ESMAP. 2019. "Global: Expanding Offshore Wind to Emerging Markets". Washington, DC: World Bank. Accessed: 30 April 2020.

Federaal Planbureau en Statbel (2020) Demografische vooruitzichten 2019-2070 Bevolking en huishoudens D/2020/7433/6.

Frumkes, D.R. (2002) The status of the California Rigs-to-Reefs Programme and the need to limit consumptive fishing activities. ICES Journal of Marine Science 272-276. Doi:10.1006/jmsc.2002.1289.

Kruse, M. et al. (2019) Market analysis Decom Tools - Interreg North Sea Region – Project Number: 20180305091606 Eco-Innovative concepts for the end of offshore wind energy farms lifecycle.

Kruse, M. et al. (2020) Stakeholder analysis Decom Tools - Interreg North Sea Region – Project Number: 20180305091606 Eco-Innovative concepts for the end of offshore wind energy farms lifecycle.

Luengo, M. and A. Kolios, "Failure Mode Identification and End of Life Scenarios of Offshore Wind Turbines: A Review," Energies, vol. 8, pp. 8339–8354, aug 2015.

Sayer, M.D.J., Baine, M.S.P. (2002) Rigs to Reefs: A critical Evaluation of the Potential for Reef Development Using Decommissioned Rigs. Journal of the Society for Underwater Technology Vol. 25, No. 2, pp. 93-97

Statistiek Vlaanderen (2018) Jouw gemeente in cijfers Oostende https://www.statistiekvlaanderen.be/sites/default/files/docs/GM-Oostende.pdf

Sun ,H., Gao, X. and Yang, H. (2019) Investigation into offshore wind farm repowering optimization in Hong Kong International Journal of Low-Carbon Technologies 2019, 14, 302–311.

Topham,E., Gonzalez,E., McMillan, D. and João, E. (2019) Challenges of decommissioning offshore wind farms: Overview of the European experience Journal of Physics: Conference Series, Volume 1222, WindEurope Conference and Exhibition 2019 2–4 April 2019, Bilbao,Spain.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

Weekers K,.(2017) Het aantal tweede verblijven in het Vlaamse Gewest in 2016 Studiedienst van de Vlaamse Regering (SVR) (https://www.statistiekvlaanderen.be/sites/default/files/atoms/files/aantal-tweede-verblijven-vlaanderen.pdf)

Wuppertal Institut (2020) „Policy Brief – Infrastructure needs of an EU industrial transformation towards deep decarbonisation", based on research project funded by EIT Climate-KIC. Task ID: TC_2.11.1_190229_P259-1B, Wuppertal/Berlin, June 2020.

Zwaenepoel E., Danckaert S. & Van Gijseghem D. (2016) Klimaatverandering in de polders. Kiezen voor zoet of zilt?, Departement Landbouw en Visserij, Brussel. D/2016/3241/279

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### 3.1.9 Planning

Most of the current SD pilot model structures presented in Vensim were defined with a number of relevant data and model equations in mind so that full quantification in the next steps should be feasible. Nevertheless, at times assumptions were made based on what appeared common sense and in the coming months additional data and model equation collection will be needed. An inventory of missing data/equations will be made based on the current pilot model structures and this will then be forwarded to the relevant MAL actors who can help with their expertise. Further consultation with the MAL actors/stakeholders involved is also planned as is interaction with WP3/WP5 partners to ensure the model scope is in line with their expectations.

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

### 3.2.1 Problem scope of the land sea system

South West Messinia (SW Messinia) is a representative example of an interlinked coastal-inland area in the Eastern Mediterranean region well known for its unique beauty and long history (Figure 29).

*Figure 29: A view of the SW Messinia case study from Palaiokastro (check view point in Figure 30).*

It is a rural area with small towns and villages (Figure 29). The landscape is mainly dominated by olive-trees, which were planted during the 1970s replacing other types of crops (Maneas et al., 2019). Part of the case study is designated as an Integrated Tourist Development Area (ITDA), which is one of the biggest tourist investments in Greece, and a major driver for the economy for the area. At the core of the case study lies a coastal wetland which is part of a wider Natura 2000 site, that includes a variety of Mediterranean habitats and cultural sites (Birds directive 2009/147/EC; Habitats Directive 92/43/EEC).

Tourism is expanding and goes hand in hand with infrastructure development (hotels, roads and airports), the creation of new job opportunities and it can provide opportunities for diversified livelihoods, but also increases the pressures on agricultural, water resources management and the environment (Tiller et al., 2019; Maneas et al., 2019; Klein et al., 2014). The area produces olive-oil of high standards, but the current conditions (land fragmentation, willingness to cooperate) add limitations on the sustainability and growth of the sector (Tiller et al., 2019). In addition, the production of olives is mainly based on conventional farming practices (e.g. tillage, use of pesticides, herbicides and synthetic fertilizers) which result to higher run-off from agriculture and subsequently environmental degradation of coastal and marine areas (Tiller et al., 2019; Berg et al., 2018). The operation of pomace-mills, located in industrial zones outside the catchment area, should ensure that olive-mill's waste from the oil production process are not disposed to the environment, but are treated as useful by-products which are further processed to produce other types of olive-oil and products (Tiller et al., 2019). However, not all olive-mills follow the regulations and their operation has impacts to the environment. Meanwhile, the wetland is in a bad environmental state, and unless

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actions are taken towards the restoration of hydrological conditions and the enhancement of its ecosystem services, it is expected that it may soon collapse with implications to fishing and tourism.

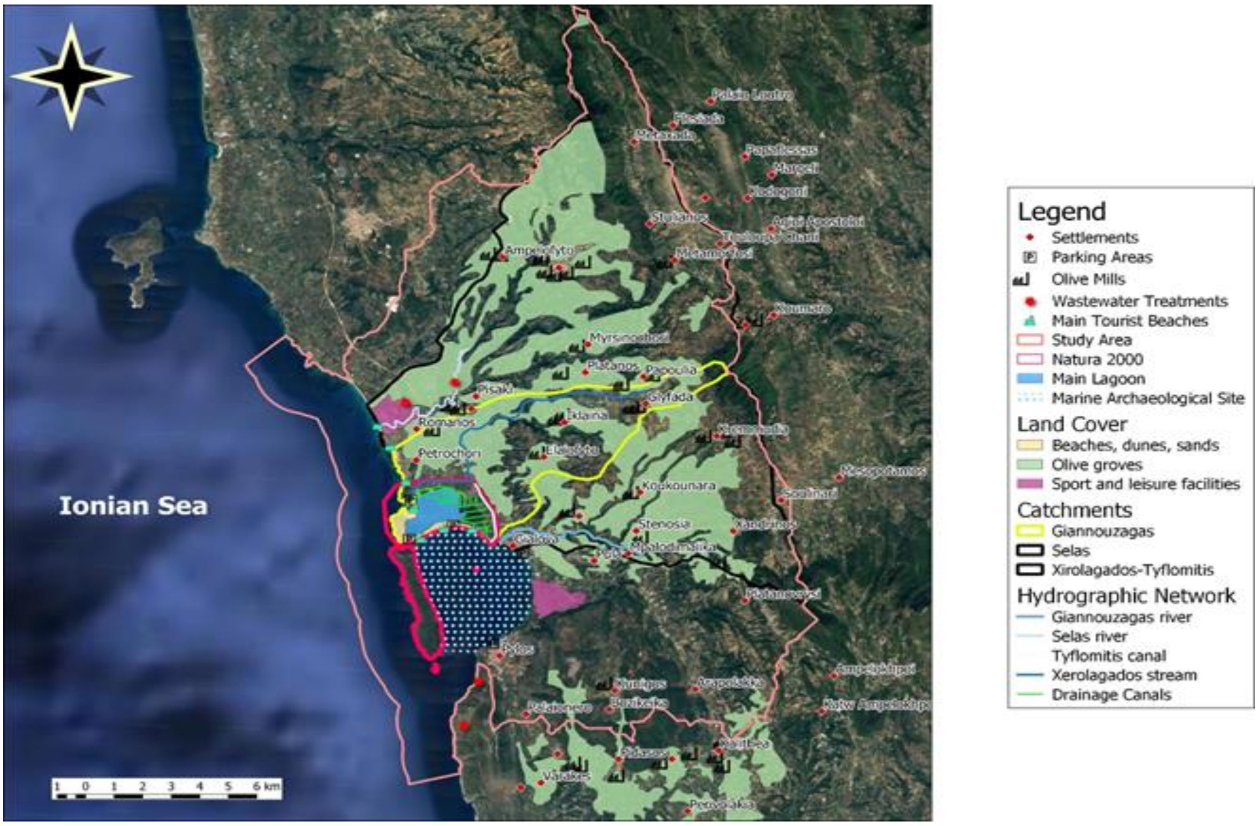


*Figure 30: Land uses and pressures in the SW Messinia (Pantazis, 2020 ).*

According to our stakeholders, the main constraints for the sustainable development of the area are the lack of trust and cooperation within and among the sectors of economy. The lack of marine and terrestrial spatial planning further implicates the challenges and limits the options for achieving better conditions (Tiller et al., 2019). These, combined with gaps in legislation and poor enforcement (Tiller et al., 2019) constrain the possibility of adopting and supporting a common vision about the area.

During the first MAL workshop, the common vision for the area was summarized as: “Join forces in creating the **Brand Name of Sustainable Messinia** that expands across all sectors, activities and products” (Tiller et al., 2019). Thus, the model scope was determined based on the outcomes and feedback from the first MAL workshop (Tiller et al., 2019), and our current understanding of the system (Androni & Eleyhteriadi, 2019; Faulwetter et al., 2019; Hatzianestis et al., 2019; Maneas et al., 2019; Manzoni et al., 2019; Berg et al., 2018; Klein et al., 2014; Bousbouras et al., 2011; Koutsoubas et al., 2000). Starting from current conditions, the basic aim of the model is to show how:

- a shift to more integrated farming practices;
- the restoration and enhancement of ecosystem services in the Gialova Lagoon wetland;
- a shift from beach tourism to thematic sustainable destination tourism.

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can create the baseline for achieving the common vision for the area (Tiller et al., 2019). Even in a small area like SW Messinia, the system is quite complex, and there are different levels of details for each of the components. Thus, our approach is based on dividing the whole model into sub-models which when combined connect all the different land-sea interactions that are important for our case.

The land-sea interactions we will consider in the model are:

- The potential of integrated farming as a model for olive-oil farming and its effect on the sustainability of the sector, the cyclic economy, the impacts on the wetland, the coastal zone and the diversification of tourism.
- How increased freshwater inputs could create better conditions in the wetland and the effects on wetland and coastal fishing and diversification of tourism
- The potential for sustainable tourism including marine tourism activities (such as diving tourism, pescatourism etc) and land agro/eco-tourism activities which would reduce the negative effects of tourism for the local population and the environment.

All sub-models will consider possible effects of climate change (temperature changes, precipitation, desertification vulnerabilities etc.).

### 3.2.2 From Multi actor analysis to modelling

During the multi actor analysis, the participants were asked to identify the potential of further development in and between their sectors and issues linked to the business opportunities and innovations that were discussed during the sectoral workshops. 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 the Messinia region.

Indeed, increased monitoring and remote sensing in the farm could benefit both the agricultural and the public sector reducing the impact to the environment. New technologies in the farm could lead to optimized use of water/natural resources and prudent use of agrochemicals (reducing farmers' costs) and to a more effective management/follow-up of the whole production process (from farm to fork), generating more free-time for farmers (improving farmers' well-being). Such agriculture could be more attractive to young generations. Coupling new technologies with authenticity could boost the local/regional olive-oil production and create new high-quality products. Agri-, pesca- 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. 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 environment.

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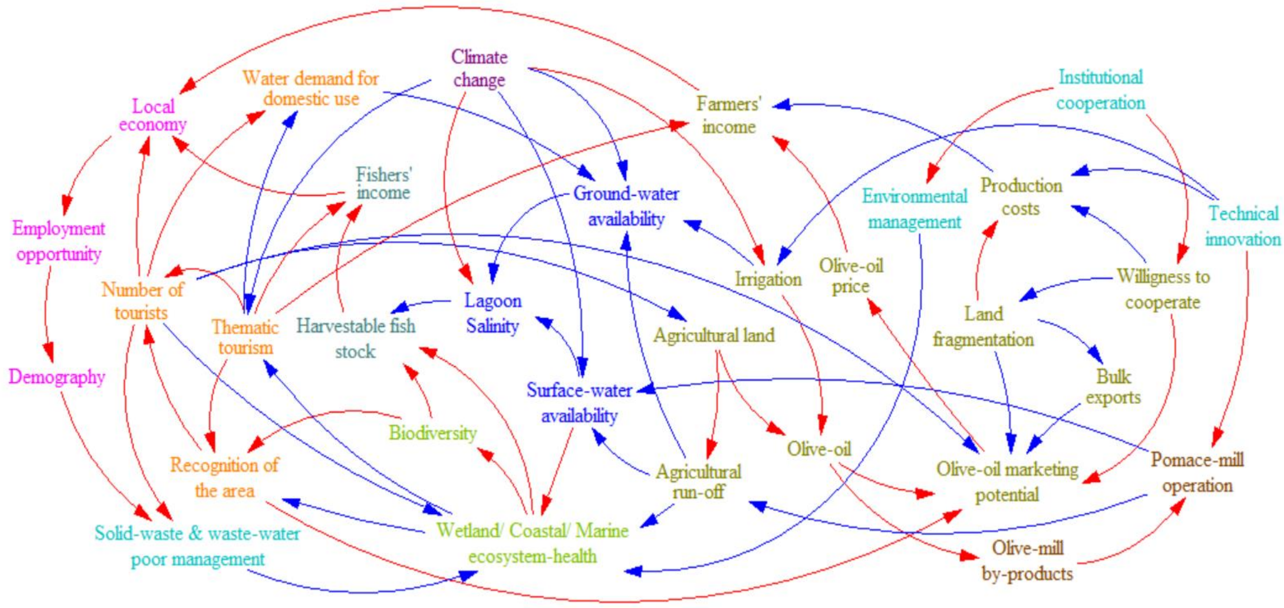


*Figure 31: A simplified overview of land-sea interactions described in the combined CLD model (Tiller et al., 2019). Pink colour is used for components linked to population, orange for components linked to tourism, blue for components linked to water resources, light green for components linked to the environment, dark yellow for components linked to agriculture, brown for components linked to local industry, dark teal for components linked to fishing, teal for components linked to institutions and innovation, and purple for climate change.*

### 3.2.3 Pilot model 1 design: Wetland salinity regulation and enhancement of ecosystem services

#### *3.2.3.1 Model scope for the wetland salinity regulation*

The model scope was determined based on the outcomes of the first MAL workshop (Tiller et al., 2019), and our current understanding of the system (Maneas et al. ,2020; Androni & Eleyhteriadi, 2019; Faulwetter et al., 2019; Hatzianestis et al., 2019; Maneas et al., 2019; Manzoni et al., 2019; Bousbouras et al., 2011; Koutsoubas et al., 2000).

The brand name of Sustainable Messinia cannot be adopted if the natural ecosystems of the area are not in a good environmental status. Starting from current conditions, the basic aim of this sub-model is to show how **the restoration and enhancement of ecosystem services in the Gialova Lagoon wetland** can contribute to achieve the common vision of the area. Fish management in the wetland is important to sustain fish stocks at sea. Furthermore, the wetland due to its high educational, environmental and aesthetic value, and the recent touristic development in the area, has the potential to become a world-known eco-touristic attraction (bird-watching, leisure-fishing, nature-trails, cultural-trails), supporting the local economy all year around.

The main challenge that needs to be addressed is the regulation of salinity. Over the years, the combined effects of increased salinity and limitation in water circulation have led to extensive reed and cattail mortality, which are typical habitats for water birds (Maneas et al., 2019). The survival of commercially important fish species found in the lagoon, is also affected by salinity. Under future drier and warmer conditions, salinity in the lagoon is expected to increase even more, unless

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freshwater inputs are enhanced by restoring hydrologic connectivity between the lagoon and the surrounding freshwater bodies (Manzoni et al., 2019).

The part of the CLD that it is relevant to the model scope is shown in Figure 32. The regulation of salinity is mainly a problem of salt mass and water volumes, and in this sub-model we will focus on these parameters. However, agricultural practices, demography and tourism have an effect on the amount of water available for the wetland. Irrigated farmland and agricultural land, tourism and demography are an input in this CLD and as such assumed to be unaffected by the processes described by the CLD for the current model. Variables related to climate change (precipitation, temperature/evaporation) are included as input to the model and assumed to be independent of the processes in the model. A more holistic approach of the system, based on data availability and understanding of land-wetland interactions could pave the way for reducing conflicts between lagoon fishers and farmers. During the sectoral workshops, these conflicts have been reported as a barrier for past wetland water management efforts. Aspects from the MAL2 CLD which are only indirectly related to the model scope such as 'harvestable marine fish stock' and linked interactions are not considered in this model.

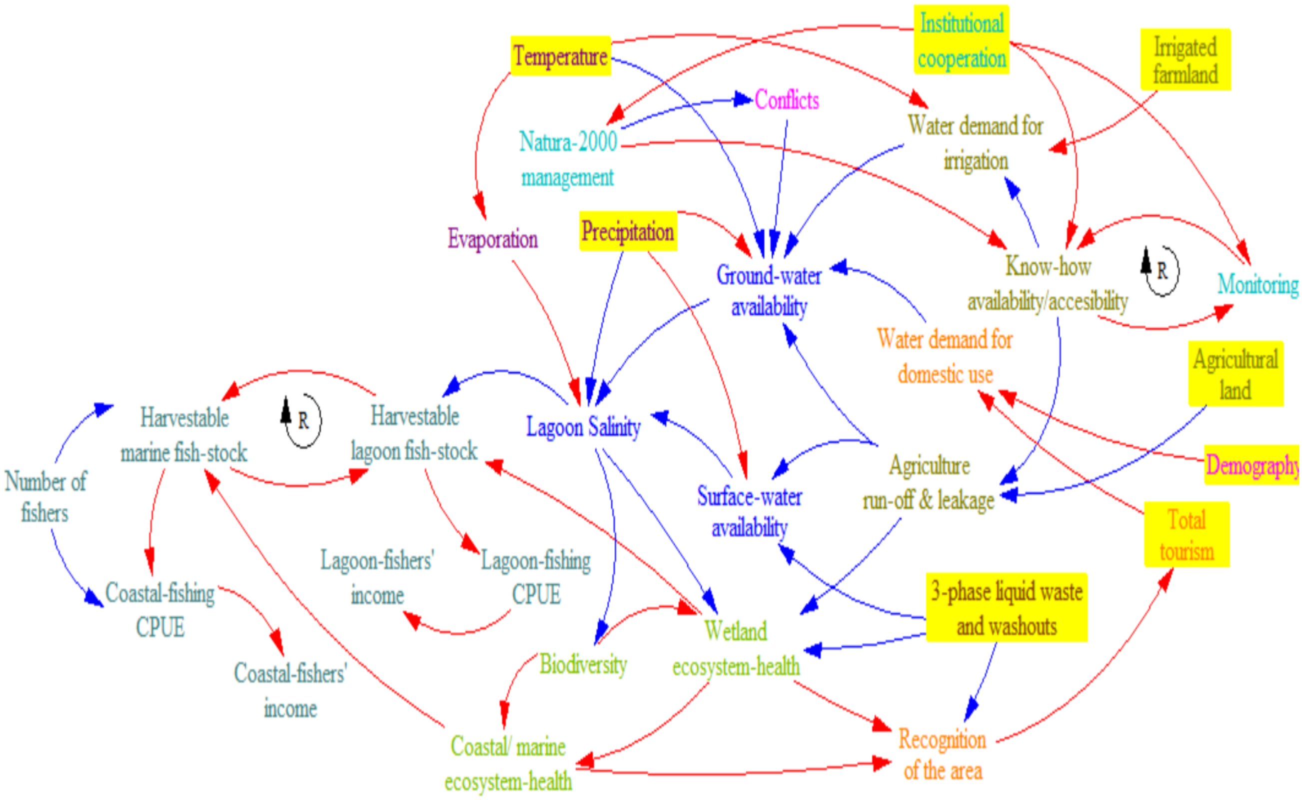


*Figure 32: Part of the MAL2 CLD that relates to the model scope (yellow: inputs) (Tiller et al., 2019). Pink colour is used for components linked to population, orange for components linked to tourism, blue for components linked to water resources, light green for components linked to the environment, dark yellow for components linked to agriculture, brown for components linked to local industry, dark teal for components linked to fishing, teal for components linked to institutions and innovation, and purple for climate change.*

#### 3.2.3.2 Quantification of the wetland salinity regulation

From discussions with experts and local stakeholders a model for salinity regulation in the wetland should contain the following processes:

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- Flora and fauna species have a specific tolerance to salinity that is critical to their survival, and when salinity exceeds certain limits the ecosystem becomes toxic to organisms;
- Climate change is expected to result in higher temperatures, and in changing precipitation, evaporation and evapotranspiration patterns. This could result in reduced fresh water availability from the aquifer, increased salinity and prolonged hypersaline conditions;
- Groundwater availability is critical for lowering the salinity levels. However, irrigation and domestic supply are based on groundwater resources. For the case of Tyflomitis-Xerolagados catchment, an increased demand has an effect on the groundwater aquifer which supplies the wetland with fresh-water inputs;
- Surface water from the catchment is regularly polluted with liquid wastes from the operation of 3-phase olive-mills and cannot be used to enrich the wetland;
- Run-off and leakage from agriculture may affect surface and groundwater quality increasing the impact of nutrient load to the wetland;
- The lack of water management both for nature and for people can create conflicts which could result in decreased availability of fresh water inputs to the wetland.

While most of this is reflected in the partial MAL2 CLD (Figure 32) there are some differences which the original CLD neglects:

- The outflow from Tyflomitis groundwater aquifer is collected to ditches. While this water could be used as fresh water input to the wetland it is also used for irrigation or diverted to sea;
- The discharge of Xerolagados River is also diverted to the sea;
- Fish species tolerance levels to salinity, will be the guide for determining which should be the optimum salinity variations, after regulation actions. We will use the salinity preferences of sea-bream, a species that prefers water bodies with relatively high salinity (Tiller et al., 2019), and has an optimum between 30 and 40 g/L.

To account for this the CLD was adapted (Figure 33). The model calculation period is taken to be from 2020 to 2100 and follows a monthly time step to accommodate for the monthly changes in farm practice, visitors, and the main climatological drivers. The optimum highest salinity value will be set at 40g/L, which is the tolerance level of sea-bream, a species that prefers water bodies with relatively high salinity. The model is applicable to the Tyflomitis-Xerolagados catchment. The conversion of the CLD starts with the identification of the stock variable(s). Once these are identified we consider the flows that increase and decrease these stocks and what auxiliary variables are needed in the calculation process. In the text we have added references to the CLD variables in Figure 33 whenever possible. These can be recognized as they are in italic.

In the SD model that corresponds to the wetland salinity regulation part of the CLD depicted in Figure 33 the main stock variable is the lagoon salinity. That is because due to human interventions, the main water bodies of the wetland are divided to the lagoon, which is well defined and covers an area of 250ha, and the wetlands (Maneas et al., 2019). The wetlands' area is changing due to changes in water level and it is difficult to define (approximately an area of 140 ha). During the wet season, when freshwater inflows are at their maximum, the water level in the wetlands is increasing and the water flows first to the lagoon and then to the sea (Maneas et al., 2019). The opposite happens during the dry season when due to high evaporation and the absence of freshwater inflows the level in the wetlands is low.

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On an annual basis, lagoon salinity values tend to increase during the spring and throughout the summer, reaching high values in late summer or early autumn (Manzoni et al., 2019). On an annual basis, the lagoon salinity is dependent on fresh-water inputs/outputs and saline-water inputs/outputs, but the effect of these variables changes depending on the season (Figure 34). During the wet season, lagoon salinity will decrease due to precipitation, fresh water inputs from the catchment, and lagoon saline-water outputs to the sea . At that time lagoon salinity will increase due saline-water inputs from the sea (tide effect). The latter may cause differences on an hourly or daily basis, but on a monthly or seasonal basis the effect is negligible. During the dry season, fresh water inputs from the aquifer are limited and only precipitation may decrease lagoon salinity. At that time lagoon salinity will increase due to fresh water losses (evaporation), and water inputs from the sea. However, when salinity values in the lagoon become higher than those at sea, saline-water inputs from the sea will have a decreasing effect on lagoon salinity. Several variables (e.g. fresh water inputs from the catchment; water inputs from sea; saline-water outputs to sea, and more as the model is structured) are not shown in the CLD, but are needed in the SD model to correctly model the dynamics of the system.

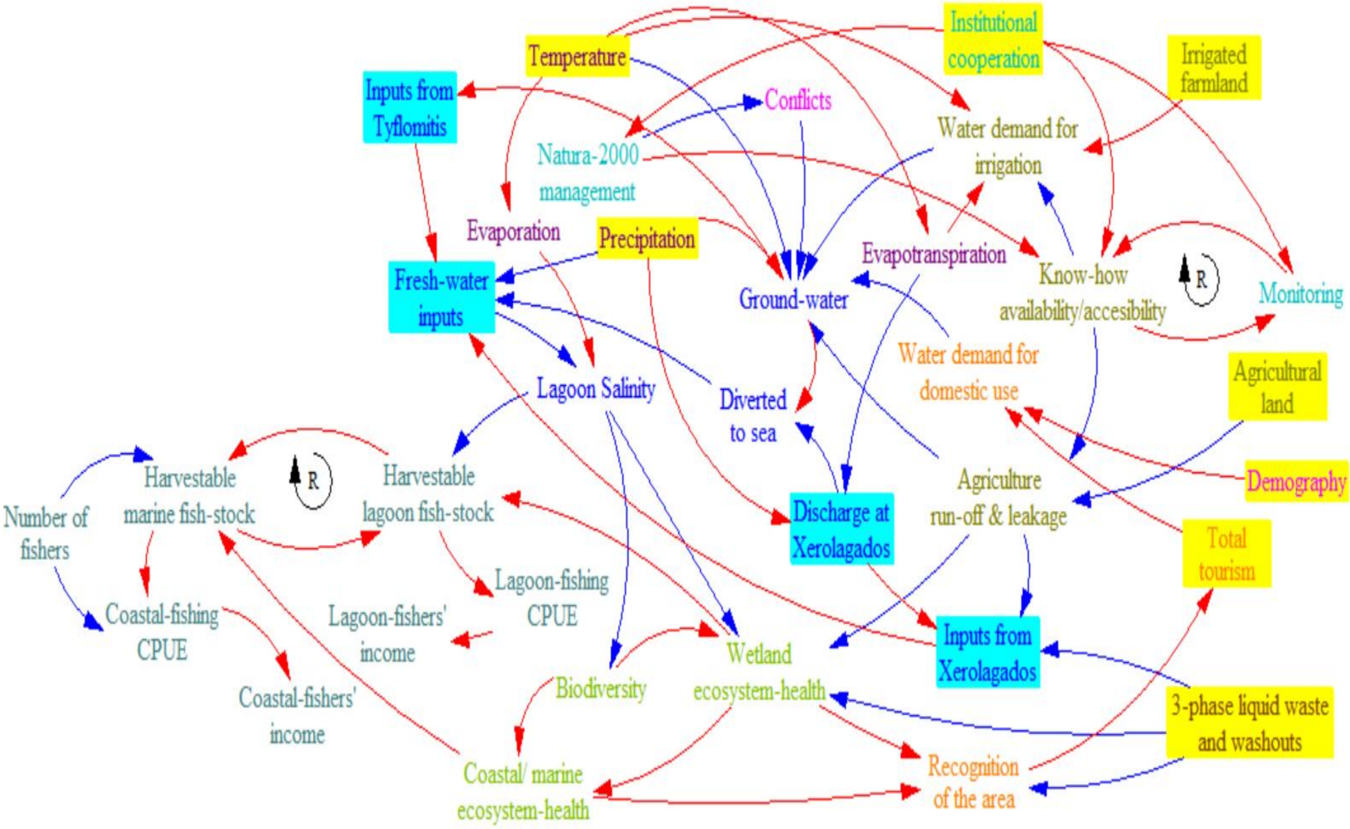


*Figure 33: Part of the MAL2 CLD adapted (blue background) to include current limitations in flows. Pink colour is used for components linked to population, orange for components linked to tourism, blue for components linked to water resources, light green for components linked to the environment, dark yellow for components linked to agriculture, brown for components linked to local industry, dark teal for components linked to fishing, teal for components linked to institutions and innovation, and purple for climate change.*

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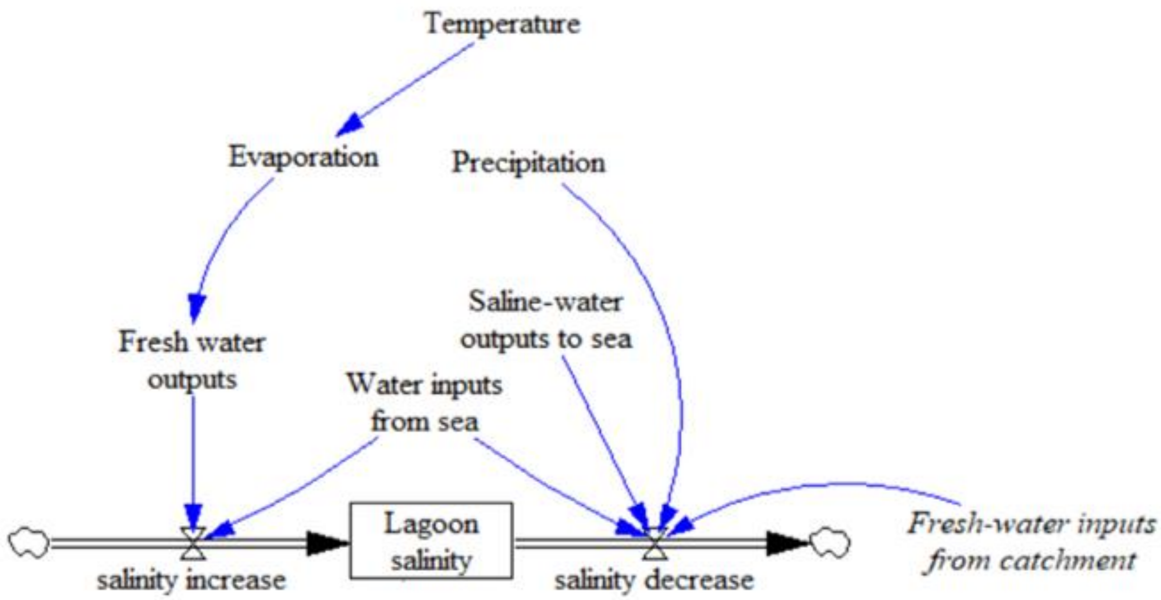


*Figure 34: SD model structure for the wetland salinity regulation.*

The freshwater inputs from the catchment are viewed as another stock of the SD model (Figure 35). The maximum fresh water available from the catchment is the sum of catchment discharge at Xerolagados ditch, at Tyflomitis ditch and at scattered springs (inside the wetland). Surface-water discharge at Xerolagados is dependent on precipitation, evapotranspiration and the ground-water level. Ground-water discharge at Tyflomitis ditch and scattered springs occurs due to overflow of the ground-water aquifer and is analogous of the ground-water level. However, the volume of water that enriches the wetland is reduced because part of the water collected in the ditch is diverted to the sea.

At present all the volume from Xerolagados ditch is diverted to the sea due to pollutants. In addition, during the summer period, water from Tyflomitis ditch and the scattered springs is used for irrigation. At present, there is no regulation for water uses from the ditch and uncontrolled irrigation could lead to conflicts with lagoon fishers, as has happened in the past.

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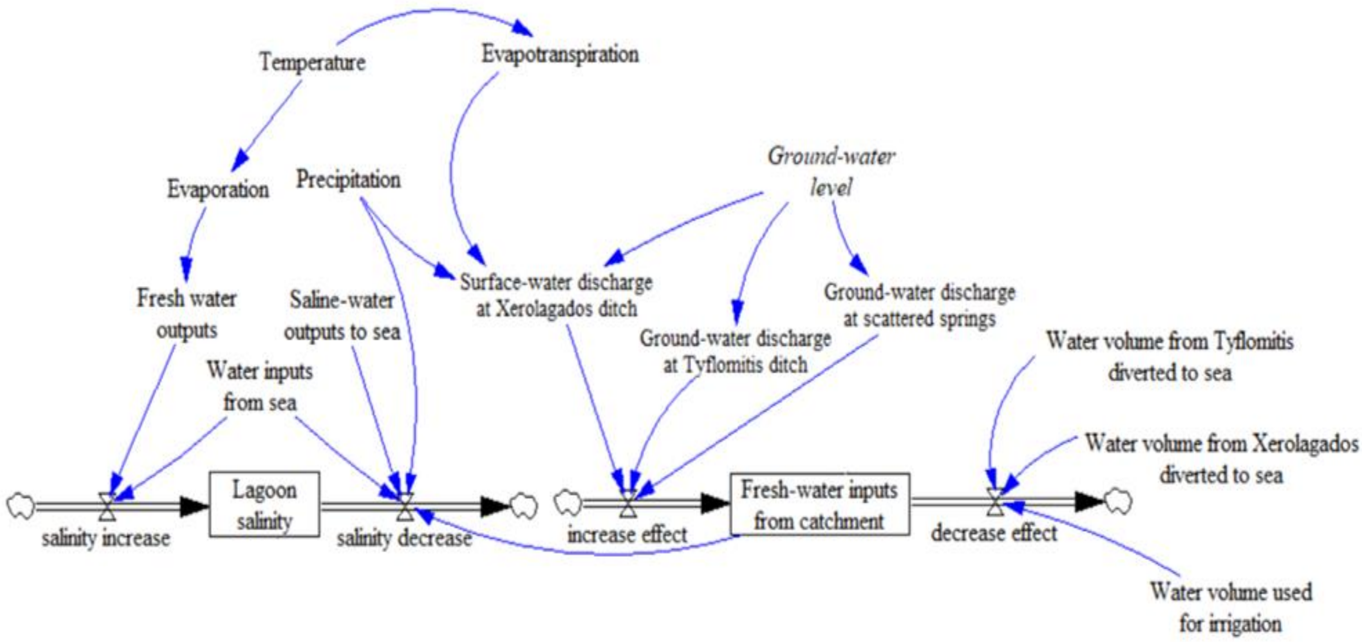


*Figure 35: SD model structure for the wetland salinity regulation.*

During the wet season, the ground-water level will gradually increase as the result of precipitation, and once it reaches a specific level it will start to outflow to Tyflomitis ditch and scattered springs and as surface-water via Xerolagados stream. The groundwater aquifer is also used for water supply and irrigation, variables which are both higher during the dry period.

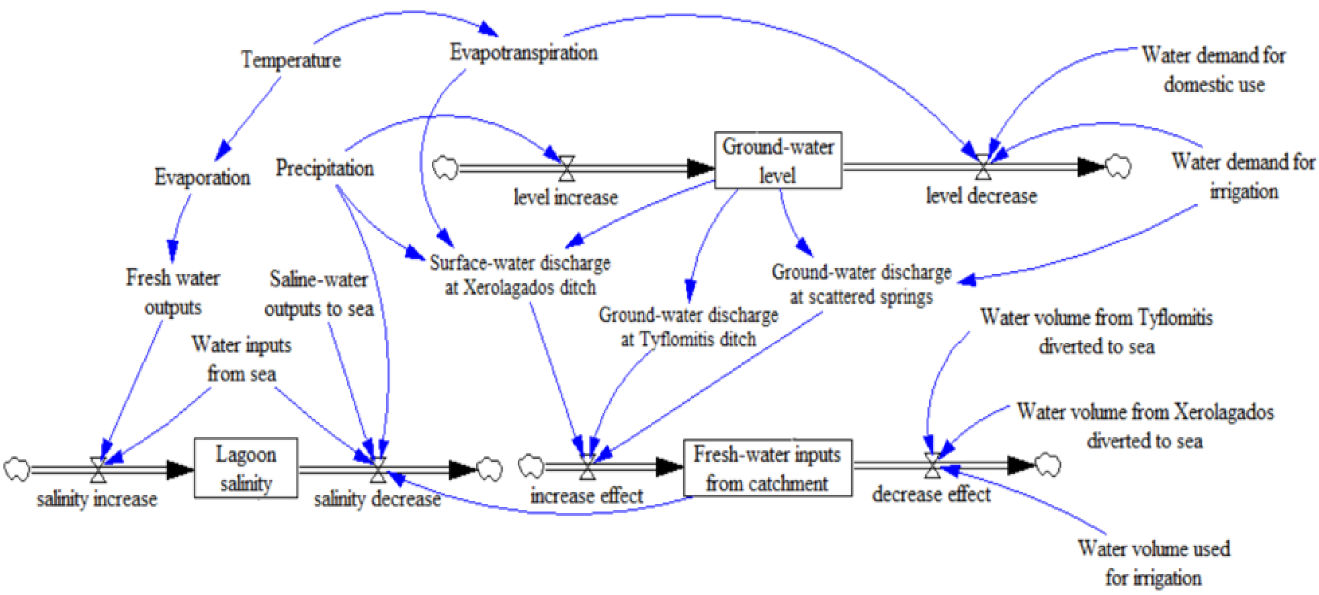


*Figure 36: SD model structure for the wetland salinity regulation.*

At present, the lagoon is hypersaline for almost 30% of the year (Manzoni et al., 2020). Fish species have a limited tolerance to salinity and increased levels could cause fish mortality thus decreasing the available harvestable lagoon fish. Invasive species could also cause fish deaths. Fishing yields also remove fish from the system. New fish, enter the lagoon from March to June.

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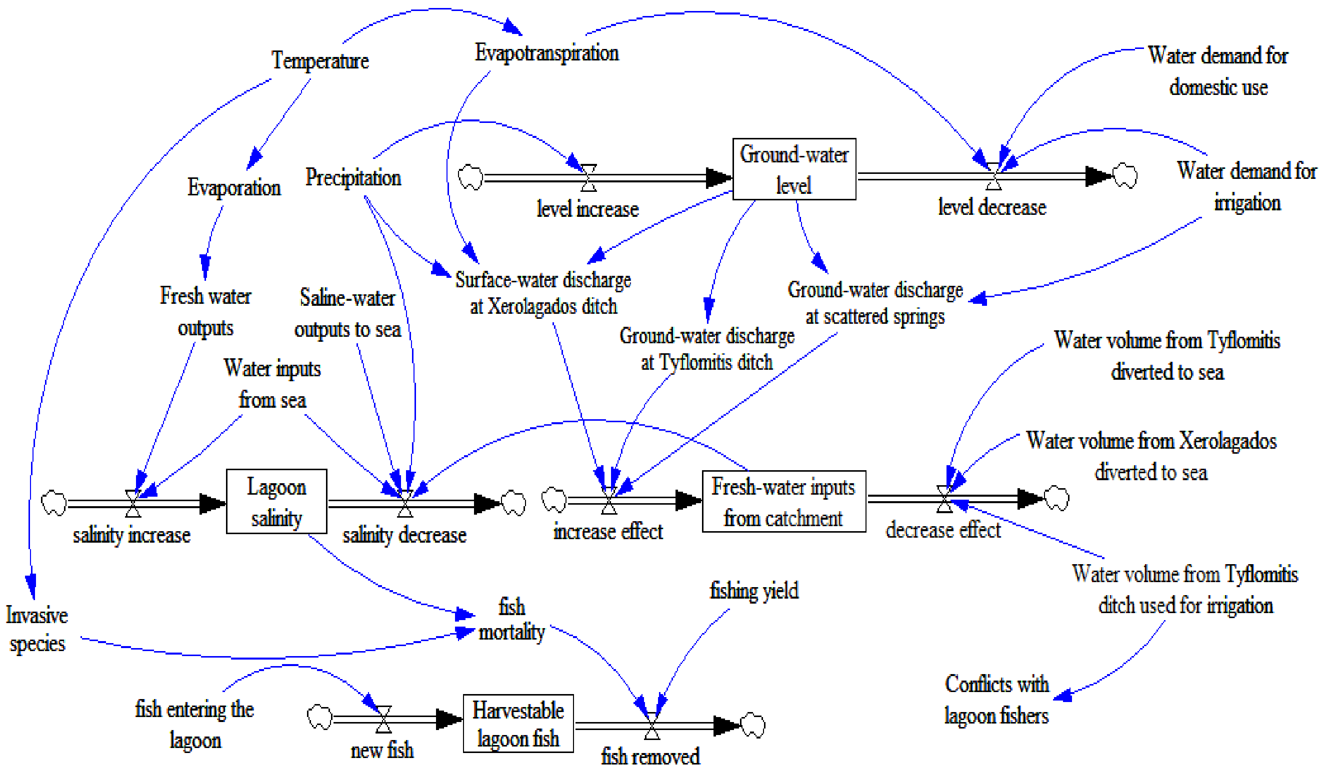


*Figure 37: SD model for the wetland salinity regulation.*

## 3.2.4 Pilot model 2 design: Shift from conventional to integrated farming

### *3.2.4.1 Model scope for of the shift from conventional to integrated farming*

The model scope was determined based on the outcomes of the first MAL workshop (Tiller et al., 2019), and our current understanding of the system (Holmering, 2020; Myers et al., 2019; Berg et al., 2018; Salguero Engstrom, 2018; Kjellström, 2014; Xenios, 2013).

The part of the CLD that it is relevant to the model scope is shown in Figure 38. Messinia is considered as one of the most important regions regarding the production of extra virgin olive oil in Greece. Some of the farms are irrigated and most of them are cultivated based on conventional practices (e.g. tillage, use of pesticides, herbicides and synthetic fertilizers) which result in higher run-off from agriculture and subsequently environmental degradation of coastal and marine areas (Tiller et al., 2019; Berg et al., 2018). More intensively farmed olive areas can reduce the quality of the product and can also generate health impacts from pesticides and herbicides. These drawbacks can make farms less competitive on the market by impacting on their sustainability and product quality, and there is a need to improve the olive-growing sector's management practices, by optimizing their resource use in a more effective and sustainable way.

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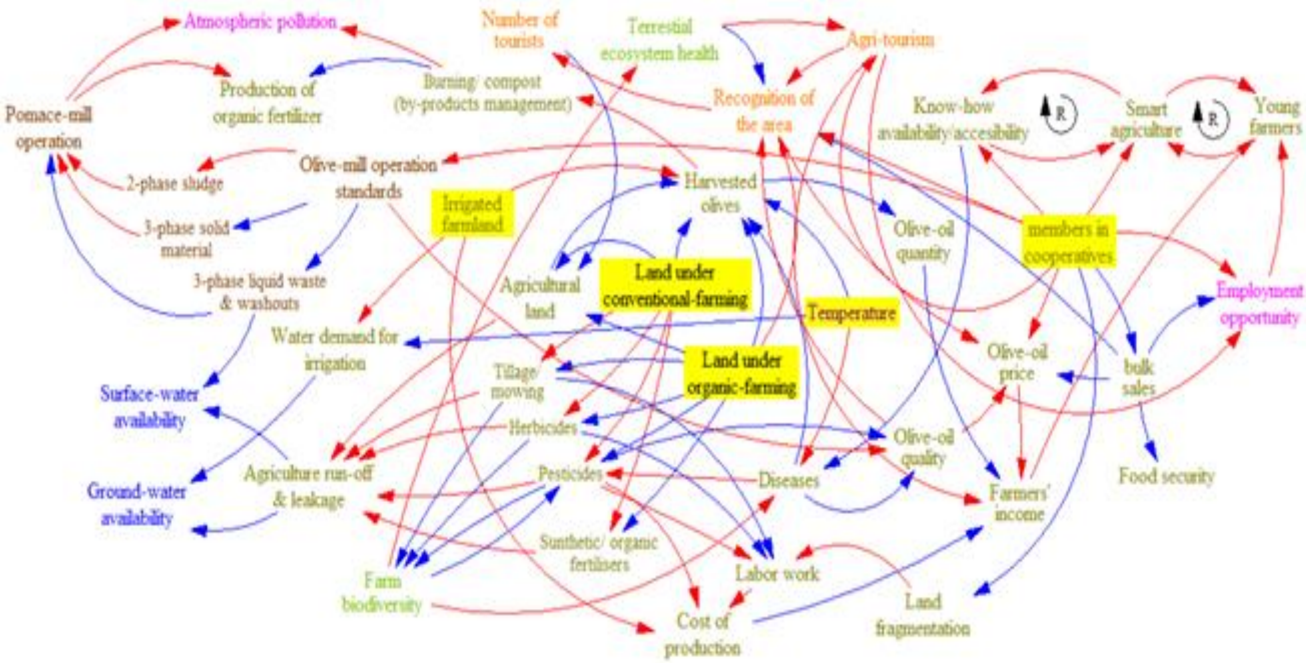


*Figure 38: Part of the MAL2 CLD that relates to the pilot model 2 scope (yellow: inputs) (Tiller et al., 2019). Pink colour is used for components linked to population, orange for components linked to tourism, blue for components linked to water resources, light green for components linked to the environment, dark yellow for components linked to agriculture, brown for components linked to local industry, dark teal for components linked to fishing, teal for components linked to institutions and innovation, and purple for climate change.*

According to our stakeholders, Greece cannot compete with Italy and Spain with regards to olive-oil volumes (Tiller et al., 2019). However, olive-oil production in Greece, and especially in Messinia has the benefit of producing high quality olive-oil (PDO) due to climate conditions and soils, and the benefit of authenticity since the harvesting is still based on traditional practises due to morphology. Nevertheless, the sector is not organised, and most of the production is exported in bulk (Tiller et al., 2019).

More sustainable agriculture, needs to build on young generations, exploit technological advances (e.g. smart agriculture) and respond to new requirements (e.g. Green deal). According to the EU Green Deal Communication documents[4], despite the delay of the revised Common Agricultural Policy (beginning of 2022), the Commission will work with the Member States and stakeholders to ensure that from the outset the national strategic plans for agriculture fully reflect the ambition of the Farm to Fork Strategy. The Commission will ensure that these strategic plans are assessed against robust climate and environmental criteria. These plans should lead to the use of sustainable practices, such as precision agriculture, organic farming, agro-ecology etc. By shifting the focus from compliance to performance, measures such as eco-schemes should reward farmers for improved environmental and climate performance, including managing and storing carbon in the soil, and improved nutrient management to improve water quality and reduce emissions. The strategic plans will need to reflect an increased level of ambition to significantly reduce the use and risk of chemical pesticides, as well as the use of fertilizers and antibiotics. The area under organic farming will also need to increase in Europe. The EU needs to develop innovative ways to protect harvests from pests and diseases and to consider the potential role of new innovative techniques to improve the sustainability of the food system, while ensuring that they are safe. The Farm to Fork Strategy will

[4] https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

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also contribute to achieving a circular economy. It will aim to reduce the environmental impact of the food processing and retail sectors by acting on transport, storage, packaging and food waste. Finally, the natural functions of ground and surface water must be restored. This is essential to preserve and restore biodiversity in lakes, rivers, wetlands and estuaries, and to prevent and limit damage from floods

According to our stakeholders, a transition from conventional to organic farming is not a realistic goal (Tiller et al., 2019), at the moment. Instead they envision a future where there is a transition from conventional to integrated olive farming, and they argue that a more integrated olive farming model is the most proper way to sustain olive-oil production in the area up to specific standards (Tiller et al., 2019). However, in our study area, farmers have identified a lack of information and knowledge, as well as a lack of trust and ability for cooperation. These issues have repeatedly been identified by previous researchers in the area, and are being recognised as barriers for transformation.

Integrated farming is perceived as a selection of farming practices able to combine the benefits of conventional and organic agriculture, leading to a lesser environmental impact while sustaining a sufficient crop yield to ensure an economic profit. It uses a more planned and evidence-based approach for the application of pesticides, and similar to organic farms uses fertilisers that are naturally-derived, instead of synthetic ones (Pimentel et al., 2005; Papadopoulos 2015). Tillage and herbicide use are replaced by mowing, which reduces the risk of soil erosion (Berg et al., 2018). The hot, dry summers in southern Greece cause high evapotranspiration, and irrigation is therefore sometimes required to obtain optimal yields, even though olive trees are considered drought resistant. In integrated farming, irrigation is based on data availability (e.g. soil humidity), and not only on farmers' experience or habits which quite often result in overuse of groundwater resources (Tiller et al., 2019). These practices could mitigate the impacts of soil erosion and agricultural run-off on the environment and favour farm biodiversity which can attract visitors if agri-tourism is further supported by regional policies. In principle, integrated olive-farming requires high standards of olive-mills for olive-oil extraction eliminating the contamination of surface waters by the operation of 3-phase olive-mills. A better link with the pomace-mill industry, could create a circular economy model where farmers use organic fertilizers produced in the pomace-mills. As analysed during the MAL workshop (Tiller et al., 2019), farms under integrated farming can be managed as one big-farm, if the farmers will be willing to cooperate under this specific goal. This will increase food security, and create a brand name for the olive-oil production which should lead to reduced bulk exportations, increased marketing potential, and thus profit for the farmers. Farmers will also be benefited by reduced costs due to sharing of knowledge and resources.

#### 3.2.4.2 Quantification of the shift from conventional to integrated farming

For developing the pilot SD model for the shift from conventional to integrated farming, we will greatly depend on the variables and the connections described in the relevant CLD. However, since the initial CLD refers to organic farming we will have to proceed to some adaptations, which are described below in text and are shown in Figure 39.

After discussions with local experts and to avoid complicating our CLD, we have replaced the variable land under organic farming with the variable land under integrated farming which will be a main stock in our model. For simplification we will consider, land under organic farming as part of the integrated farmland (see also below SD structure).

This can happen without changing the links and the polarities in our model. Based on discussions with local experts, under integrated farming, the use of tillage and herbicides is not allowed, the use of pesticides is expected to be reduced due to a more prudent evidence-based application, and fertilizing is mainly based on naturally derived products (Holmering, 2020). Thus, from an environmental point of view, the impact of integrated farming on the environment is similar to the one of the organic (with the exemption of pesticide uses), and the connections will keep the same

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polarity. With regards to production and tree coverage, in our study area organic farms contain on average 185 (±55) trees/ha and produce on average 1090 lt of olive oil per hectare, while conventional farms contain about 210 (±75) trees/ha and produce on average 1140 lt/ha (Berg et al., 2018, extended information in Salguero Engstrom, 2018). Under integrated farming we could assume that the per ha number of trees and olive-oil production will be optimized to values between those mentioned above, thus the polarity with harvested olives can remain the same. In the long run, it is expected that a shift to integrated farming will lead to higher area recognition, and increased olive-oil price income following processes similar to those described for organic practices.

After discussions with local experts, it is evident that the support of cooperatives is fundamental for enabling the transition from conventional to integrated farming. Cooperatives will play a crucial role in providing knowhow and services and in the adapted CLD we have changed the variable Know-how accessibility/availability, which is difficult to model, with the variable budget to sustain cooperative services which is also a stock for our model (see below). The connection with smart agriculture is no longer a loop. Smart agriculture, can be considered as a service which provides the necessary data for the application of integrated farming. In addition, we have added the variable land under cooperative scheme which will also be a stock.

The model calculation period is taken to be from 2020 to 2100 to include climatic parameters and it will follow a monthly time step to be compatible with the rest of the model. For those parameters for which only annual data are available these will be repeated for the individual months or, in case of flows, spread evenly over months. The operation of cooperatives is of crucial importance to support the transition from conventional to integrated farming, and a prerequisite for achieving the vision of a strong brand name behind Sustainable Messinia. However, in our study area in particular, the memberships are few. Our stakeholders complain that cooperatives are a waste of money there is a lack of trust in cooperative management that prevails among farmers (Tiller et al., 2019). This issue of lack of trust has been reported by researchers before and is related to a historical way of how cooperatives run. However, it is suggested that a more modern type of cooperative or collaborative business can have different outcomes if farmers are convinced to participate.

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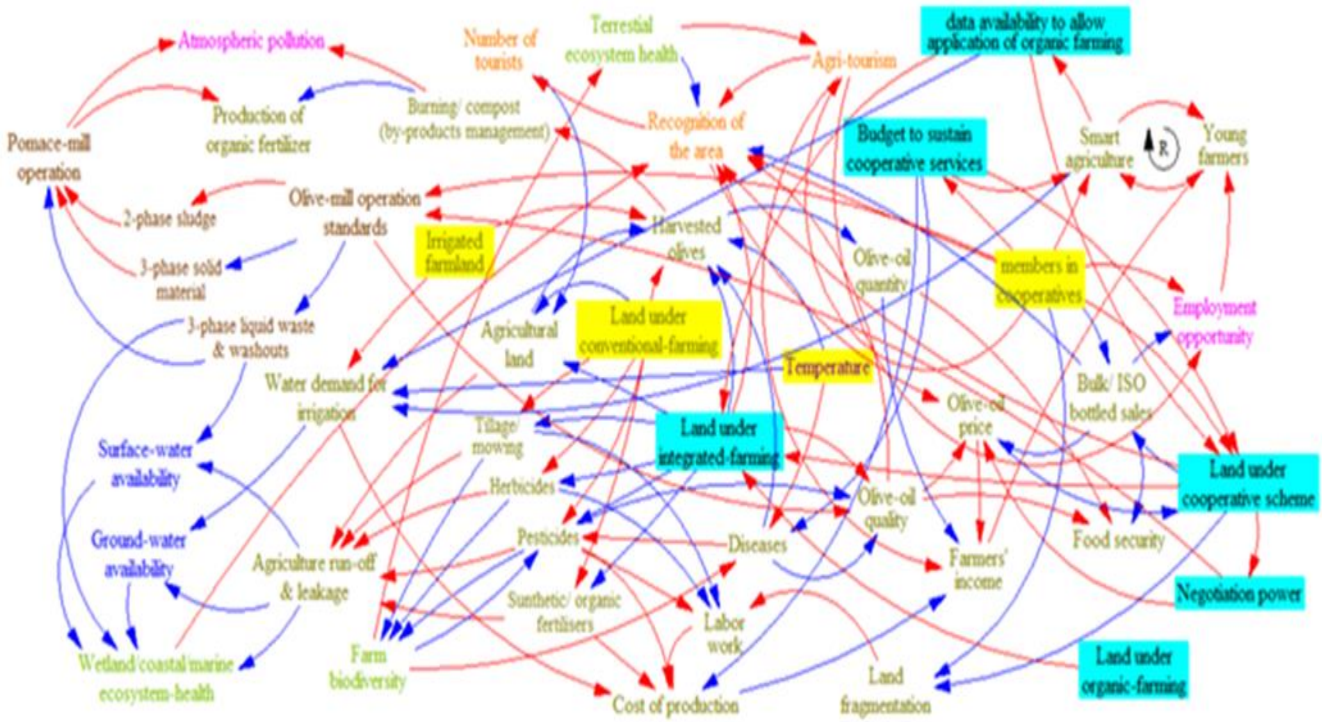


*Figure 39: Part of the MAL2 CLD adapted (blue background) to include processes necessary to describe a shift from conventional to integrated farming. Pink colour is used for components linked to population, orange for components linked to tourism, blue for components linked to water resources, light green for components linked to the environment, dark yellow for components linked to agriculture, brown for components linked to local industry, dark teal for components linked to fishing, teal for components linked to institutions and innovation, and purple for climate change.*

In our sub-model (Figure 40), the support of cooperatives is fundamental for enabling the transition from conventional to integrated farming. For a start, the promotion of the common vision to farmers already participating in cooperatives could without doubt create a critical mass of farmers willing to participate in such transformation. Their examples and experience can be used as case examples and guidance to other farmers, who may have a more sceptic approach and need more time and evidence before acting. The olive-land under cooperative scheme will be further increased by members who will be tempted to have access to subsidized services (converted to area when multiplied with owned land). Subsidies to cooperatives for developing services could without doubt strongly mobilize farmers to become part of a cooperative.

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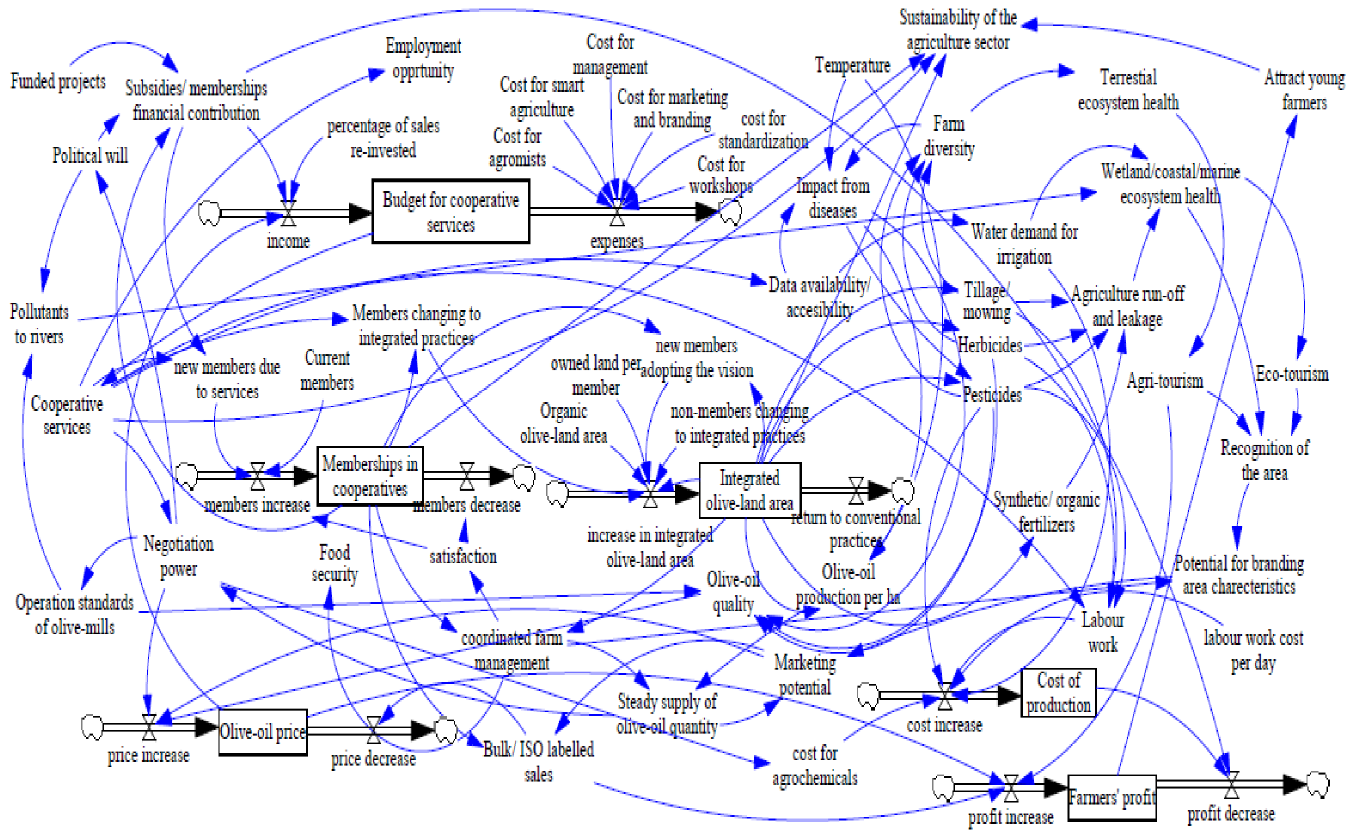


*Figure 40: The model for the shift in Agriculture from conventional to integrated farming.*

Cooperatives will play a major role in providing knowhow and supporting agronomists for full time farming consultation to all members, support the application of smart agriculture and relevant data management with support from academic experts, take over the task of branding, marketing and promotion under the guidance of relevant experts. Subsidies to cooperatives should be case specific, depending on the budget of cooperative services as mentioned above, until the cooperative can become self-sustained by its memberships and sales. Under current economic conditions, farmers who choose to become members will not have to support financially the cooperative, and they can benefit from the operation of the cooperative without further costs. The number of subsidies (amount) is depended on Political will or/and the participation in projects. However, the members should be committed to support financially the cooperative after the pass of the subsidized period to ensure long term operation. Another important income for the cooperatives will come from sales of certified olive-oil. Regarding the Integrated olive-land area, we will assume that at present, only areas under organic farming meet the demands to be designated as integrated, thus at each year: Integrated olive-land area = (Land under organic practices) + (Land shifted to integrated).

Under integrated farming, the use of tillage and herbicides is not allowed, thus the transformation should reduce the risk of soil erosion and eliminate the use of Glyphosate in the farms. With regards to pesticides, an evidence-based approach could reduce the amount of pesticides per hectare, also decreasing potential residues in olive-oil and improving its quality. Fertilising is based on naturally derived products instead of synthetic ones. The above combined could decrease agriculture run-off and leakage with benefits to the wetland ecosystem, and increase the capacity of the farms to support biodiversity, similar to organic farms. However, the use of pesticides, even more prudent, will still pose a threat to biodiversity. Increased diversity in the farm could be branded to increase the marketing potential but also support agritourism. Water consumption for irrigation could be reduced to optimum since it will be based on data availability on soil and tree needs. To ensure the brand name of Sustainable Messinia and high-quality olive-oil, a strong cooperative, could increase

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the demand of high operation standards of olive-mills, excluding operations which still pollute the rivers. The operation of this type of olive-mills could be controlled by the relevant authorities.

As more land will be under integrated farming, this will pave the way for branding the area characteristics adding to final selling price. This could increase food security in terms of a steady and sustainable olive-oil production, from farm to fork. Under the current situation with Covid-19, and possible similar threats in the future, increased food security may become a prerequisite for consuming and trading and the sector runs the risk to be left outside the market if no actions are taken.

According to our stakeholders, bulk exports consist of almost 90% of the total exports. Under integrated farming, and strong cooperatives, this huge amount of olive-oil could be branded, marketed and promoted to meet the needs of the global market, with increased profit for the farmers. A steady supply of the market, a prerequisite in trading according to local experts, could be achieved via the operation of cooperatives who should also take the task of branding, marketing and promotion based on relevant experts. The olive-oil price is expected to continuously rise due to better branding, marketing, promotion and negotiation power and less bulk exports.

To run our sub-model (Figure 40), we will simulate the shift to Tyflomitis-Xerolagados catchment. The model calculation period is taken to be from 2020 to 2100 and it will follow a monthly time step, to be compatible with the rest of the model, but as the data used are annual these will be distributed over the months. We will assume that at present, only areas under organic farming meet the demands to be designated as integrated, thus at each year:

Integrated/conventional ratio = [(Land under organic practices) + (Land shifted to integrated)]/(remaining farms under conventional farming).

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### 3.2.5 Pilot model 3 design: Shift from a seasonal Sun/Sea/Sand tourism destination to a sustainable destination with expansion of the tourism season

#### *3.2.5.1 Model scope for the shift from Sun/Sea/Sand tourism to Sustainable Thematic Tourism*

The model scope was determined based on the outcomes of the first MAL workshop (Tiller et al., 2019), and our current understanding of the system, including national and regional policy planning for the area, which identifies tourism as one of the major drivers of economy in the area.

The part of the CLD that relates to this model scope is shown in Figure 41. Tourism is being recognised as a major economic driver for the area and most regional and National development policies also recognise the need and the potential for tourism expansion in Messinia. This potential was discussed by the participants in our MAL workshop (Tiller et al., 2019), who however identified the need to change the current Sun Sea Sand tourism model, as it results in highly concentrated arrivals during the summer months which put significant temporal pressures on the environment and the natural resources (fish stock and water demand) as well as the local infrastructures such waste and wastewater management capacity. These pressures could however have a more cumulative effect especially under different climate conditions. The stakeholders recognised that they would like an increase in tourism season and a connection of the tourism industry to the agricultural and fishing activities of the region as well as a general interest to connect the tourism activities to what was recognised as the Identity or Character of Messinia. In addition, it was identified that there is land space conflict between agricultural activities and the expansion of the tourism sector and in particular the building of new hotels, which is enhanced by the lack of an overall spatial planning policy for the area. Temperature changes and other climate change characteristics were also discussed with an interest to identify possible resilience adaptations. What was not mentioned, and has since been identified is the effect of external disruptions to the tourism industries like COVID. Given the vision for Sustainable Messinia as it was described by our stakeholders we decided to approach Pilot Model 3 in 3 parts:

1) The Seasonal resource stresses of the current tourism development model;
2) The land use conflict and the pressures on the Messinian Landscape Identity;
3) The opportunities offered through differentiating the tourist product based on the cultural and geographical characteristics of the area.

Aspects of the MAL that are only indirectly related in this model, like the effects closed by the water demand to the groundwater levels and the lagoon salinity as well as the changes of farming practices that are covered with the other two pilot models are not considered again as parts of tourism model presented here. Climate change scenarios will be considered as inputs in all 3 parts of the model.

In the next section we will describe the steps taken to convert this CLD into and SD model.

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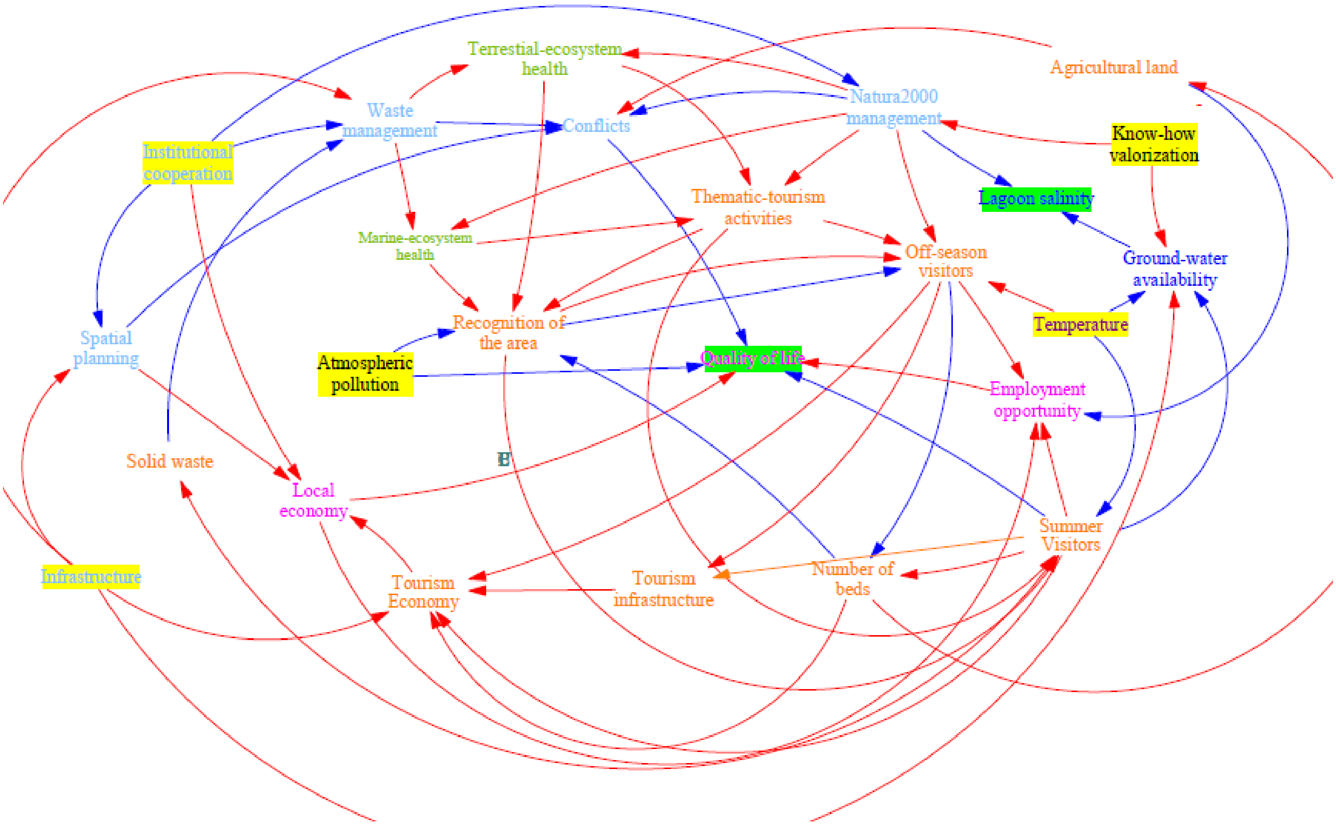


*Figure 41: Part of the MAL2 CLD that relates to the pilot model 3 scope (yellow:input, green:output) (Tiller et al., 2019). Pink colour is used for components linked to population, orange for components linked to tourism, blue for components linked to water resources, light green for components linked to the environment, dark yellow for components linked to agriculture, brown for components linked to local industry, dark teal for components linked to fishing, teal for components linked to institutions and innovation, and purple for climate change.*

### 3.2.5.2 Quantification of the shift from Sun/Sea/Sand tourism to Sustainable Thematic Tourism

For developing the pilot model for the shift of the tourism industry to more sustainable thematic tourism practices we identified that in the original holistic CLD a lot of different types of activities had been combined into one for simplification, which caused gaps in meanings and notions that were necessary for the quantification of the interactions. In addition to that, two National Policy documents were released in the meantime, both of which had direct effect on the model. Therefore, It was decided then to revisit some of the original CLDs (Tiller et al., 2019) and also identify the issues mentioned in the policy documents with direct effects on local tourism development. The CLD that will now be used for the quantification of the connections and the SD model is described in Figure 42.

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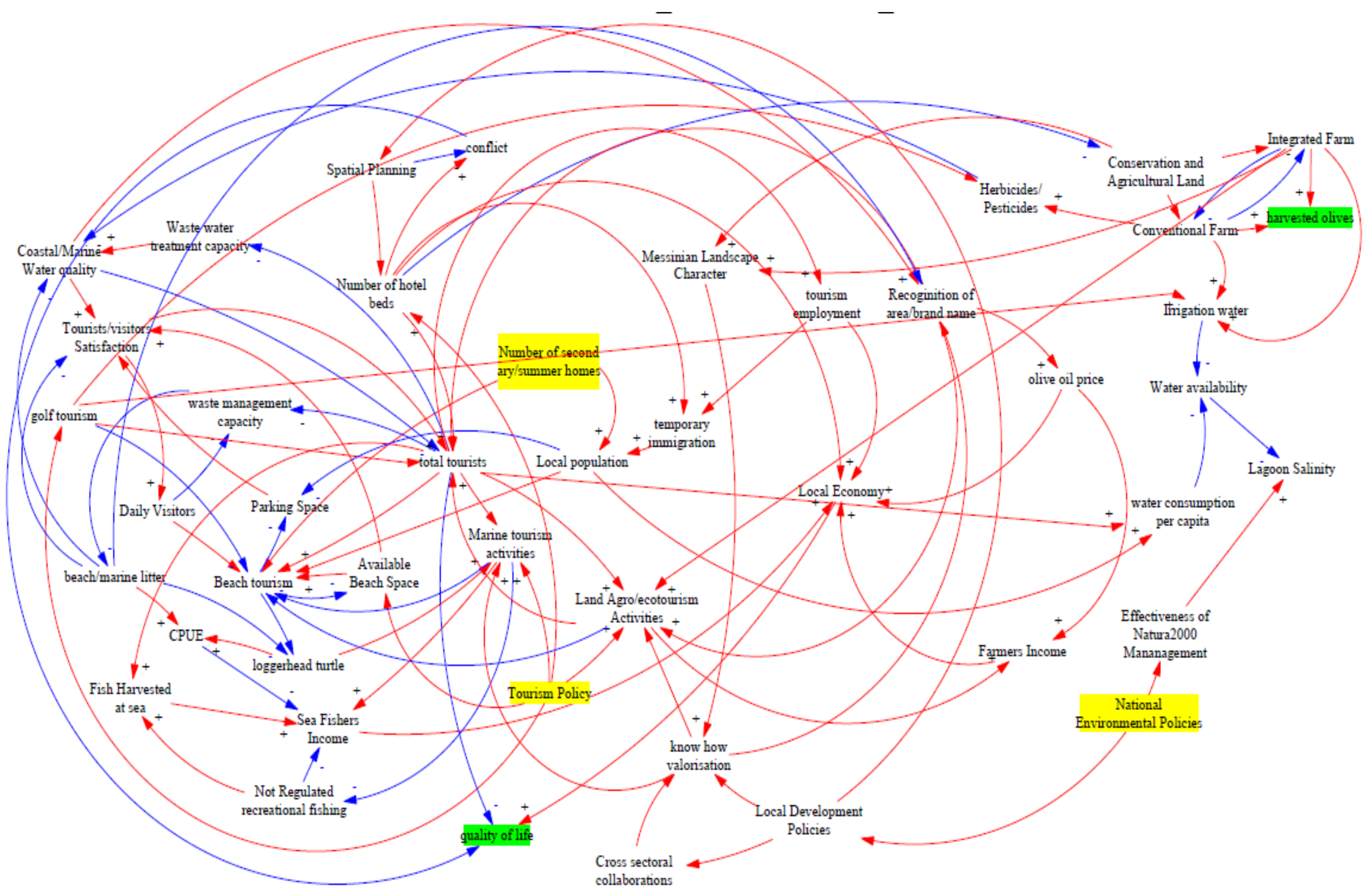


*Figure 42: CLD on which the Tourism SD pilot model will be based (Inputs:Yellow, Outputs:Green) (Red arrows show positive feedback, Blue arrows show negative feedback.*

From discussions with our stakeholders we have identified that a shift to more sustainable tourism practices would require quantifying the amount of stress on the groundwater reserves caused by the increased water demand due to the population increase during the summer months. The population increase is currently around 16% for the whole Municipality of Pylos-Nestoros (an area larger than the 3 water basins that have been identified in the MAL2 case study) however on the coastal strip there are approximately 2000 beds which corresponds to a 10% population increase. In addition to that, there are plans for increasing the capacity of beds in the area and if the tourist model doesn't include more than just the beautiful beaches then the strain will be on the water resources. In addition to the hotel beds, about 36% of the houses in the Municipality are characterised as summer homes or secondary homes. The effects of the increased water demand have been included in the analysis of Pilot Model 1, with reference to the protected area of Gialova Lagoon, thus they will not be analysed again with this model. The other problems caused by the temporal increase of population in the area are the increased waste load which for Greece is estimated to be around 1.2 kg per person per day. Similarly the Municipal wastewater facilities receive a load of approximately 150lt per person per day while the sewage treatment capacity is limited. With the expected increase in the tourism numbers these pressures are expected to intensify. The intensification of tourism activities in the area also puts pressure on land use and the Landscape Identity of Messinia in the long term, which the tourism sector also wants to maintain and improve as a branding characteristic.

The model calculation period will be from 2010 to 2100 and will follow a monthly time step to accommodate for the monthly changes in tourism numbers and activities offered, but as land use change pressures and climate change have more long term impacts it is necessary to have a long modelling period.. The conversion of the CLD starts with the identification of the stock variable(s).

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Once these are identified we consider the flows that increase and decrease these stocks and what auxiliary variables are needed in the calculation process.

In the model we have identified three stock variables

1) *Pollution* in connection with the seasonal pressures identified;
2) *State of Landscape Identity* which is related to the long term pressures of land use change;
3) Participation in *non-Beach activities*, which is one of the requirements of the tourism industry for *extension of the tourism season*, in addition to being a possible *response to the beach crowdedness.*

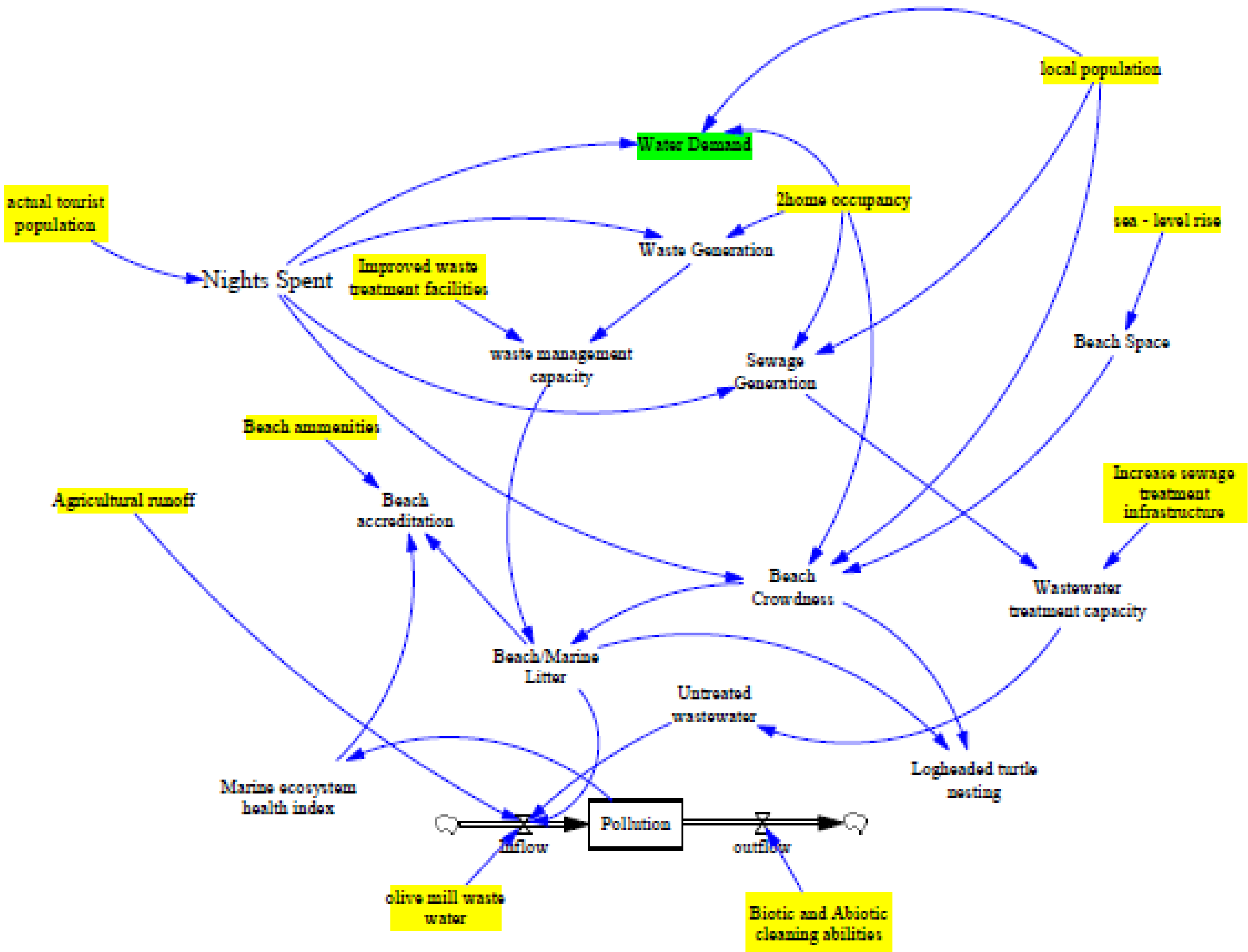


*Figure 43: Part of the tourism SD model where the seasonal pressures are identified.*

Pollution inflow is calculated as an outcome of the untreated wastewater and the olive mill waste water. The solid waste pressure on inflow will be estimated based on Jambeck et al. (2010) proposal for calculating waste input into the ocean from mismanaged land practices. The outflow is based on the biotic and abiotic capacity of the environment to self-clean. An HCMR study (the results of the study will be included as part of the update on the D2.1 deliverable) showed that in total the marine ecosystem health index of the coastal waters is characterised as GOOD or HIGH in places, but fieldtrips where organised to identify the agricultural and oil industry impact and another fieldtrip

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for model validation is being planned. Tourism pressure is calculated based on total monthly nights spent in the area, which corresponds to the total monthly increase of population. In 2018, 121.037 nights were reported in the Municipality of which 51% were recorded during the months (June, 12%, July, 18% and August 21%). The total nights spent is related to both the arrivals of tourists during the summer months but also to the average days spent per tourist. The impact on the water demand will be modeled based on an average use of 200lt per person per day, the local population and the nights spent per month by tourists and second home owners:

*(Nights Spent at hotels + Nights Spent at secondary homes +(Local population x 30 days)) x 200l = Monthly water demand*

Another seasonal issue that could potentially increase in the future is the beach crowdedness. The coastal line in the case study area is mainly rocky, with some sandy beaches (Figure 30) including the famous beaches of Voidokilia (Figure 29), Divari and Romanos. All three become crowded during the summer months and especially during August, which causes dissatisfaction among tourists as can be seen from the negative comments and bad marks on Tripadvisor. The crowdedness also impacts the nests of the sea turtles Caretta Caretta who use the same beaches as nesting grounds. If the tourism model remains unaltered and the beaches remain the major attraction, beach crowdedness is expected to increase, especially with a possible sea level rise. Beach crowdedness will be estimated based on the presence of tourists and visitors:

*Beach Space / Number of people present on beach = beach crowdedness*

These three characteristics (pollution, water demand and beach crowdedness) have seasonal profiles and through modeling we can identify short term thresholds that hinder the sustainability of tourism in the area.

The next part of the SD model, shown in Figure 44 focuses mainly on the long term impacts of tourism if there is a continuation in the trends of new building new hotels. In this case the STOCK variable is the State of the Messinian Landscape Identity. This landscape Identity is what the stakeholders called the Messinian Naturalness and they have connected with the mixed shrub olive groves agriculture that is found all over the land. Thus the initial value of which is based on the total land covered by olive groves and shrubs as well as grapevines both of which produce Products of protected origin, and in particular the olive groves are strongly connected to the identities of the local population (Loumou and Giourga, 2003). Because the idea of Landscape Identity is very much connected to local values and sense of belonging, this part of the model will also try to identify the possible impact on the social cohesion due to the increase in the number of hotels. A proxy to that and a common indicator used for this purpose is the number of beds/100 homes. Currently the value is 43.8 rooms for 100 permanently occupied homes. The changes for this part of the model are much slower than in the case of water demand and marine pollution but they do need to been taken into account with regards to the sustainability of tourism in the time frame set by the model which will be from 2010 to 2100. In this case the monthly time step will be a fraction of the annual values. There is already a trend in new hotels opening in the area as shown in Figure 45 (EOT, 2020) which will be included in the modelling process.

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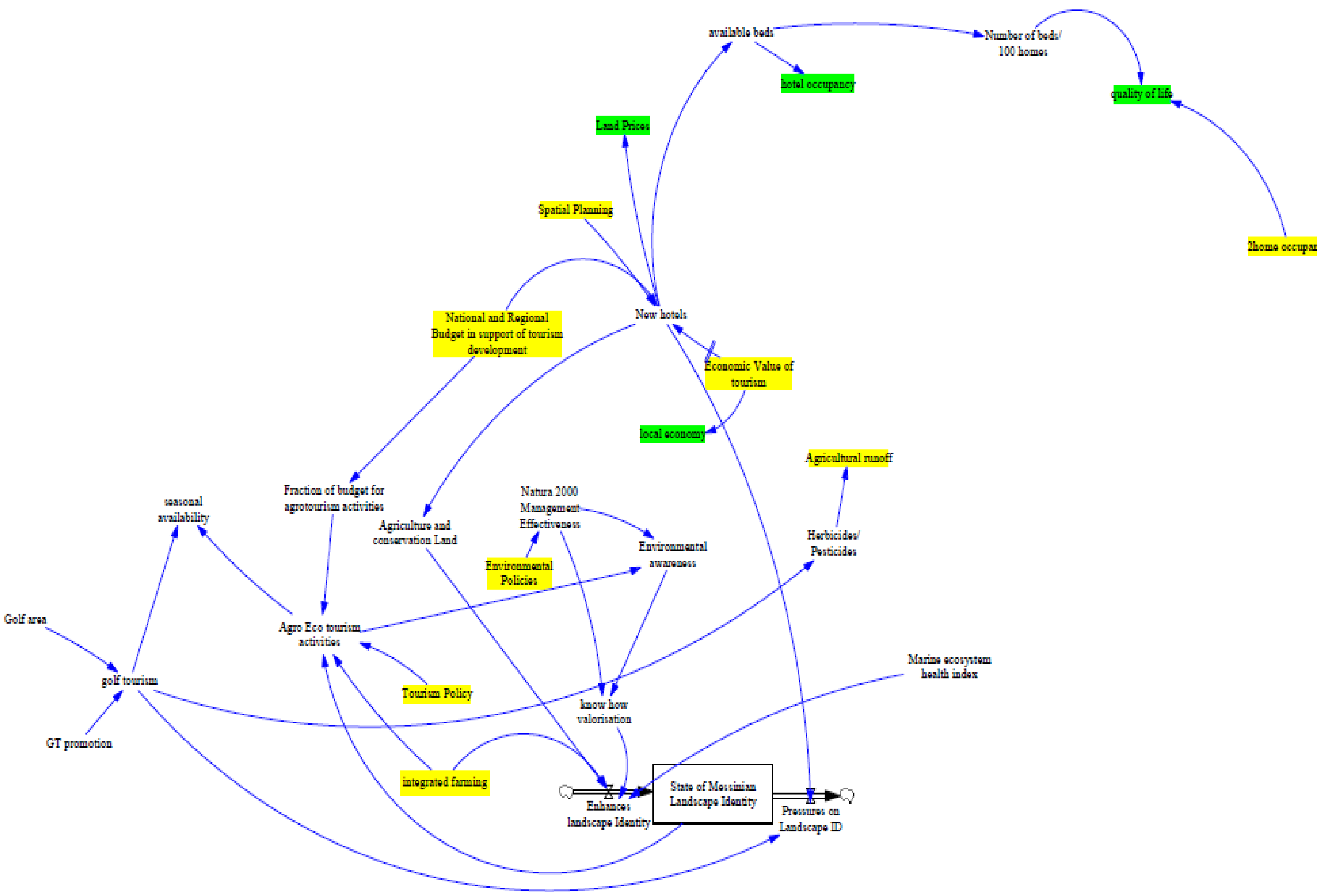


*Figure 44: Part of the tourism sub-model that shows the long term pressures on the State of Messinian Landscape Identity due to land use change.*

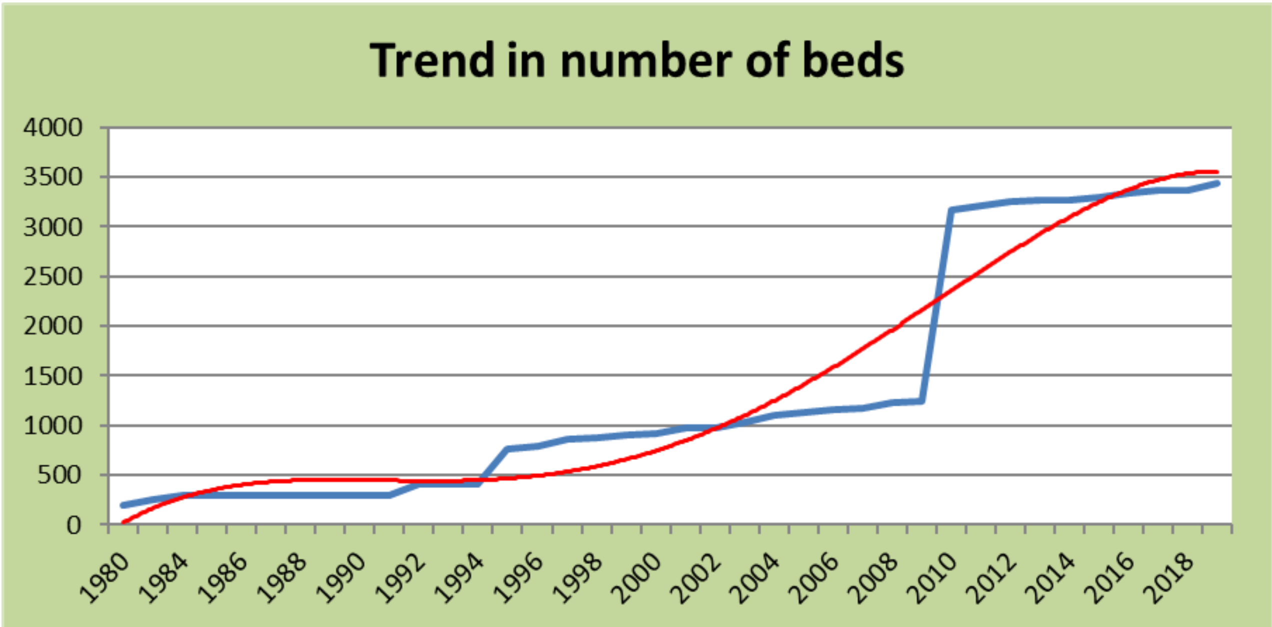


*Figure 45: A graph showing the trend in beds for the Municipality of Pylos-Nestoros.*

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The third part of the tourism sub-model (Figure 46) shows the new opportunities in tourism development that are not by default connected to an increase in the number of beds. These opportunities are based on exploiting the Image of Messinia for offering a different tourism product that can be connected to other practices such fishing and agriculture and the cultural history of the area. In this submodel the stock value is the Participation to non-Beach activities to represent the interest in shifting from the current tourism model (Figure 20). This participation is based on the availability of these activities during different times of the year. As it was identified there is a lack of thematic tourism activities connecting to other economy sectors that could help expand the tourism season and also spill over economic benefits of tourism to other sectors (Agriculture and Fishing). In May 2020 a new policy on thematic tourism was voted in the parliament which opens the door for expansion on practices like diving tourism, pescatourism, sailing tourism, agrotourism, ecotourism, sports tourism. It is important to identify in the model the seasonality of these activities, like when is the best and most interesting season for agrotourism, and identify whether they could offer an expansion of the tourism season or offer alternative practices but during the same peak times. Promotion of such activities is also very important in order to increase participation by enhancing awareness in the availability of alternative forms of activities. Through this model we will try to identify which types of activities offer the most opportunities and also how will these activities contribute to the Sustainable tourism branding identified as a goal for the tourism sector.

By changing arrivals and nights spent in the tourism model (Figure 18) we can identify weaknesses in water provision and beach crowdedness, as well as threats in pollution load due to the seasonal increase in population. Similarly over the long term through model simulation where the current trends in hotel development area sustained, we will be able to identify the possible thresholds in hotel development over which excessive development will put too much pressure on the state of the Landscape identity on which the image branding of sustainable tourism will be based. At the same time a possible expansion of the tourism season and a reduction of the beach crowdedness will be simulated through the creation of thematic tourism activities, a need that was mainly identified by the stakeholders who all showed interest in altering the current tourism model that is mainly based on beach activities.

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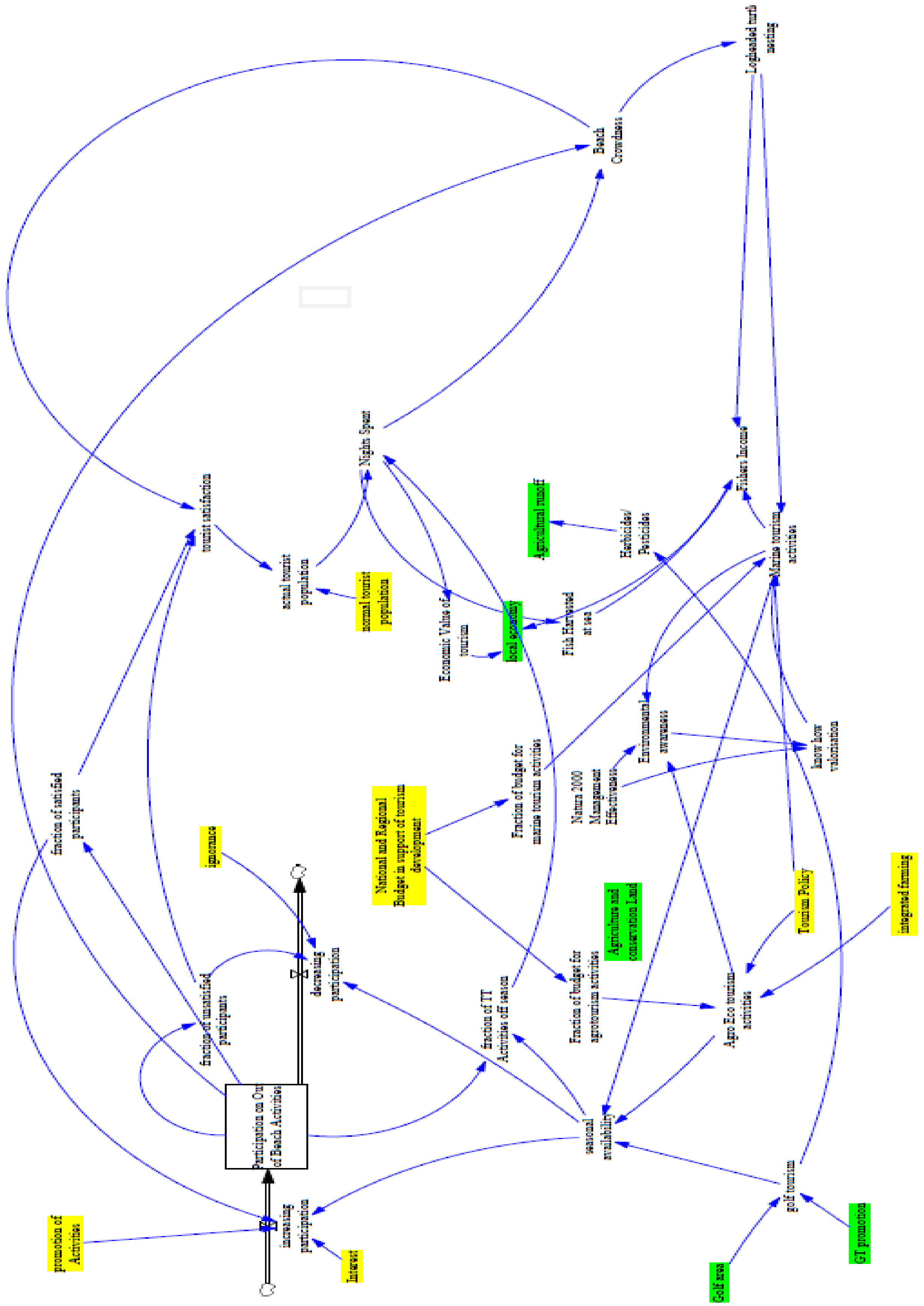


*Figure 46: Part of the tourism submodel that shows the possibilities and opportunities for Thematic Tourism activities in the case study area.*

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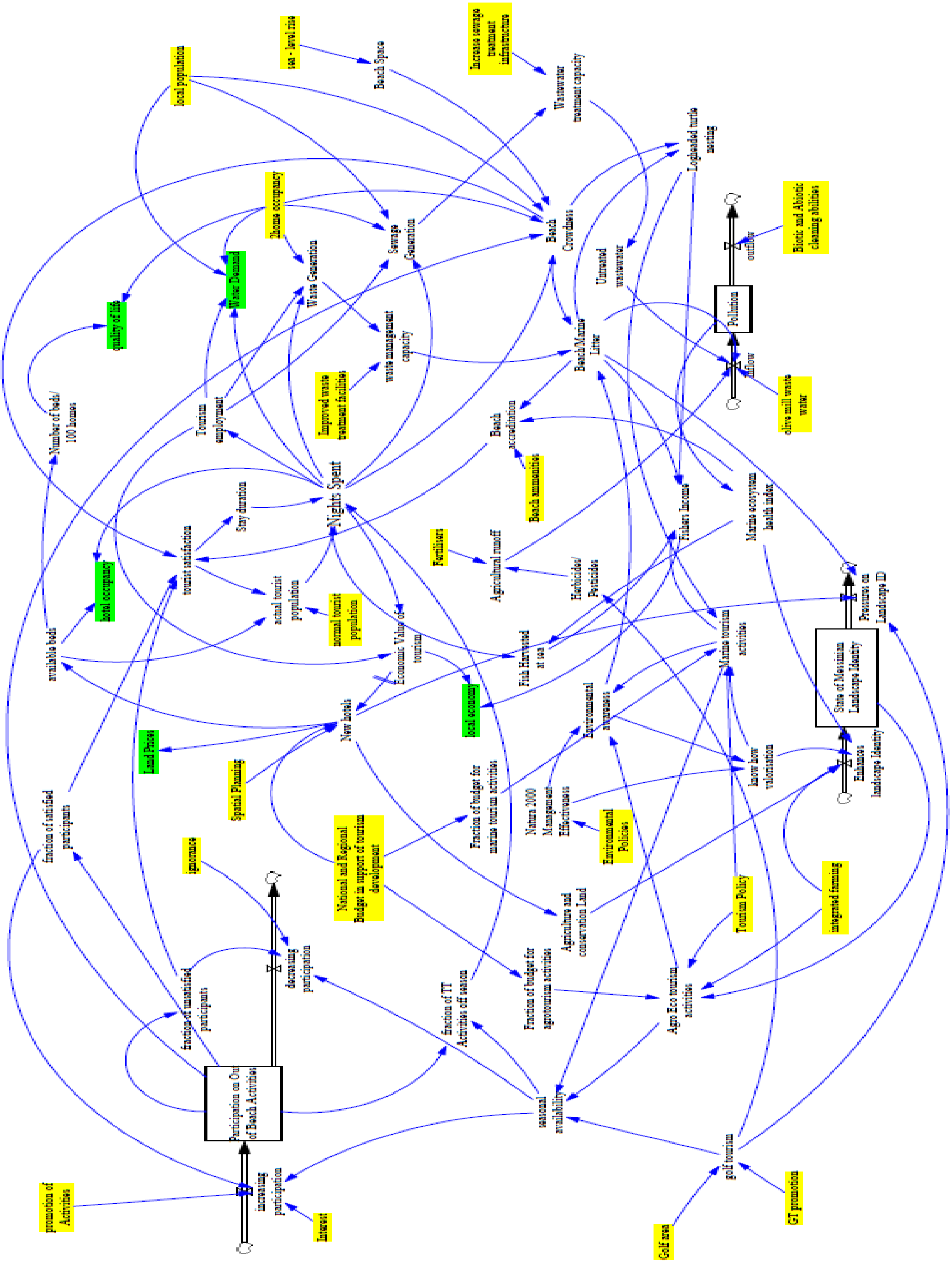


*Figure 47: The MAL 3 sub model on the Shift to the Thematic Tourism.*

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### 3.2.6 Overview of the stock-flow models and land sea interactions

For MAL 3 we have developed 3 submodels with corresponding SD model structures:
- Wetland salinity regulation and enhancement of ecosystem services (Figure 37);
- Shift from conventional to integrated farming (Figure 40);
- Shift from the seasonal Sun/Sea/Sand tourism destination to a sustainable destination with expansion of the tourism season (Figure 47).

### 3.2.7 Problems that can be addressed with the SD models

Pilot model 1 design: Wetland salinity regulation and enhancement of ecosystem services;
- Address the issue of fish stock reduction in the Gialova lagoon due to increased salinity;
- Address the issue of freshwater scarcity and overexploitation (both surface and groundwater);
- Address the issue of water pollution from agricultural activities;
- Address the lack of eco-touristic attraction of the area.

Pilot model 2 design: Shift from conventional to integrated farming
- Address the issue of product quality as well as the issue of product competitiveness in the market due to the use of agrochemicals;
- Address the issue of bad management practices in agriculture such as the bad use of water and chemicals;
- Address the lack of cooperatives' modernization.

Pilot model 3 design: Shift from Sun/Sea/Sand tourism to Sustainable Thematic Tourism
- Address the issue of seasonal pressures on water resources, coastal space and marine environment;
- Address the issue of seasonal pressures to wastewater and solid waste management capabilities of the municipality;
- Address the issue of increasing hotel development;
- Identify possible opportunities for thematic tourism activities;
- Identify the sustainability and possible impacts of these activities.

### 3.2.8 Main model variables

*Table 1: Main variables in the model (S: stock, F: flow, A: auxiliary)*

| Topic | Name | Unit | Role | Definition |
|---|---|---|---|---|
| Tourism | Participation in off beach activities | People/month | S | |
| Tourism | Pollution | Mg/l/day | S | Fraction of waste polluting |
| Tourism | State Landscape Character Identity | Hectares | S | Hectares with mixed shrubs and olive groves |
| Tourism | Nights Spent | Nights/month | A | Total number of nights recorded in hotels each month |
| Tourism | Beach crowdedness | Persons/sq. m | A | How many people visit the beach relative to total beach area |
| Shift in Agriculture | Membership in | Number of | S | |

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| | | | | |
|---|---|---|---|---|
| | cooperatives | farms | | |
| Shift in Agriculture | Integrated/conventional ratio | | S | |
| Shift in Agriculture | Budget for cooperative services | Euros | S | |
| Shift in Agriculture | Olive oil Price | Euros | S | |
| Shift in Agriculture | Farmers Profit | Euros | S | |
| Shift in Agriculture | Cost of production | Euros | S | |
| Wetland Salinity Regulation | *Lagoon salinity* | g/L | S | the salt concentration |
| Wetland Salinity Regulations | salinity increase | g/L/month | F | factors that increase salinity |
| Wetland Salinity Regulation | salinity decrease | g/L/month | F | factors that decrease salinity |
| Wetland Salinity Regulations | Fresh water outputs | m^3/month | A | fresh water outputs from the lagoon |
| Wetland Salinity Regulation | Water inputs from sea | m^3/month | A | |
| Wetland Salinity Regulations | Saline-water outputs to sea | m^3/month | A | |
| Wetland Salinity Regulation | Evaporation | m/month or m^3/month | A | evaporation for the model area |
| Wetland Salinity Regulations | Precipitation | m/month or m^3/month | A | |
| Wetland Salinity Regulation | Temperature | celcius | A | |
| Wetland Salinity Regulations | *Fresh -water inputs from catchment* | m^3 | S | fresh water volume |
| Wetland Salinity Regulation | increase effect => inflow to fresh water input from catchment | m^3/month | F | |
| Wetland Salinity Regulations | decrease effect => outflow to fresh water input from catchment | m^3/month | F | |
| Wetland Salinity Regulation | Surface-water discharge from Xerolagados | m^3/month | A | |
| Wetland Salinity Regulations | Ground-water discharge from Tyflomitis ditch | m^3/month | A | |
| Wetland Salinity Regulation | Ground-water discharge at scattered springs | m^3/month | A | |
| Wetland Salinity Regulations | Max. value | m^3/month | | maximum theoretical catchment discharge |
| Wetland Salinity Regulation | Water volume from Tyflomitis diverted to sea | m^3/month | | |
| Wetland Salinity | Water volume from | m^3/mont | | |

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| | | | | |
|---|---|---|---|---|
| Regulations | | Tyflomitis ditch used for irrigation | h | |
| Wetland Regulation | Salinity | Water volume from Xerolagados diverted to sea | m^3/mont h | |
| Wetland Regulations | Salinity | Conflicts with lagoon fishers | | conflicts due to competing demand for fresh-water resources |
| Wetland Regulation | Salinity | *Ground-water level* | m | |

### 3.2.9 Data sources

Will be added upon revision.

### 3.2.10 Planning

Will be added upon revision.

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

### 3.3.1. Problem scope of the land sea system

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 48). 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 48) 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 (HELCOM, 2017). International agreements and environmental regulations put in place since decades still have not managed to decrease the nutrient loads from land sufficiently (Destouni et al., 2017) for combating the severe eutrophication, hypoxia and algae bloom problems in the coastal and marine waters of the Baltic Sea (The Guardian, 2018). 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 (Darracq et al., 2005; Bring et al., 2015a), 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.


*Figure 48: The Baltic Sea and its catchment area with the Norrström drainage basin outlined in yellow.*

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Norrström drainage basin and the associated Swedish Northern Baltic Proper water management district (especially in its eastern parts) is under high population pressures from the expanding city of Stockholm, in addition to agricultural water-quality pressures (Destouni and Jarsjö, 2018). Various active sectors in this hydrological catchment and its coastal zones are moving towards further developments and thus are affecting each other's activities. Coastal tourism development and expansion of summer houses with temporary occupation increase water supply and wastewater facilities that are not connected to municipal infrastructures and treatment systems, which further cause inland, coastal and marine water quality issues. Therefore, coastal water quantity and quality are significantly affected by sectoral interactions on land and in the coast. Figure 49 illustrates schematically various water flux and nutrient (pollutant) contributions to total output flow and its nutrient concentration through inland surface sources, natural sub-systems and socio-economic sectors to the coastal zone (left cross-section in the schematic, Figure 49). Also, it highlights the flux and concentration contributions from diffuse subsurface sources and legacies to coastal region (right cross-section in the schematic, Figure 49).

For example, hydro-climatic changes may result in greater or/and lesser water quantity availability; on average, changes may be in one direction (e.g., increased precipitation in this region), whereas variability/anomaly frequency/severity, e.g., of both floods and droughts, can increase for both directions. This may result in too much or too little water, annually, seasonally and in extreme events on shorter time scales, e.g., for the agriculture and forestry sectors, with major economic implications for possible costly developments of additional drainage infrastructure – with further water quality and eutrophication implications, as well as new irrigation infrastructure to handle more frequent/severe drought effects – so far not available in the region. Such changes can also cause both water security and storm water handling – with associated further water quality and costly water treatment – problems in urban areas. Shifts in hydro-climate and/or cross-system/sector interactions further affect coastal water quantity and quality interactions and, needs for (further) costly measures, e.g., for pollution/eutrophication mitigation (Bring et al., 2015a). In addition, human activities in the land catchment itself (e.g., changes in extent/intensity of agriculture, forestry, industry) also affect pressures and need developments of inland and coastal water resources, e.g., seawater intrusion into coastal groundwater, and associated and more general volumetric and/or quality and treatment level needs for municipal water supply (MWS) and wastewater treatment plants (WWTP).

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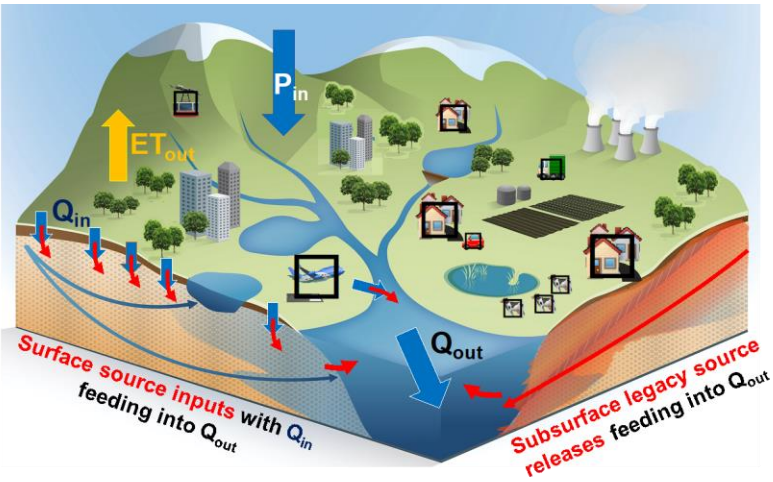


*Figure 49: Schematic of main water fluxes and different type of sources, feeding nutrient (pollutant) inputs into (from active surface sources, left cross-section) and/or releases within (from subsurface legacy sources, right cross-section) a catchment, and contributing to total concentration in the output flow to coastal region (modified version of Figure 3 in Destouni and Jarsjö, 2018).*

To account for various above-mentioned key water-related issues and their possible changes under different hydro-climatic change and sector development scenarios, the following land-sea interactions are considered in the system dynamics (SD) modelling for MAL3:

- Water availability interactions among hydro-climatic components, water sub-systems, and various key active sectors on land and in the coast, and their possible change and development scenarios affecting current and further future sector activities and socio-economic characteristics in the region;
- Contributions of changes in hydro-climate and key active sectors to coastal water interactions and their changes, with focus on implications for seawater intrusion into fresh coastal groundwater, used and needed by the coastal population and their activities, as a feedback from the sea;
- Implications of all of the above for coastal nutrient loading and eutrophication, and opportunities for their mitigation and management.

### 3.3.2. From multi actor analysis to modelling

The key interaction issues mentioned above for MAL3 resulted from the sector and multi-sectoral workshops held at Stockholm University as part of WP1 in the COASTAL project, which resulted in the main stakeholder-given unified causal loop diagram (CLD) shown in Figure 50. The regional CLD involves 31 variables that are highly interconnected through 160 connections and 567 feedback loops as shown in Figure 50. It is too complex to be taken further as a whole into the SD modelling, and data/evidence based quantification is only possible for some key interactions in the CLD, connected in different SD sub-models with specific issue focus. In the process of selecting relevant quantifiable and quantifying key system interactions and associated components and variables from the CLD, availability of quantitative observation data, model results, and other types of information was considered according to the data and model inventory developed in WP2 for MAL3.

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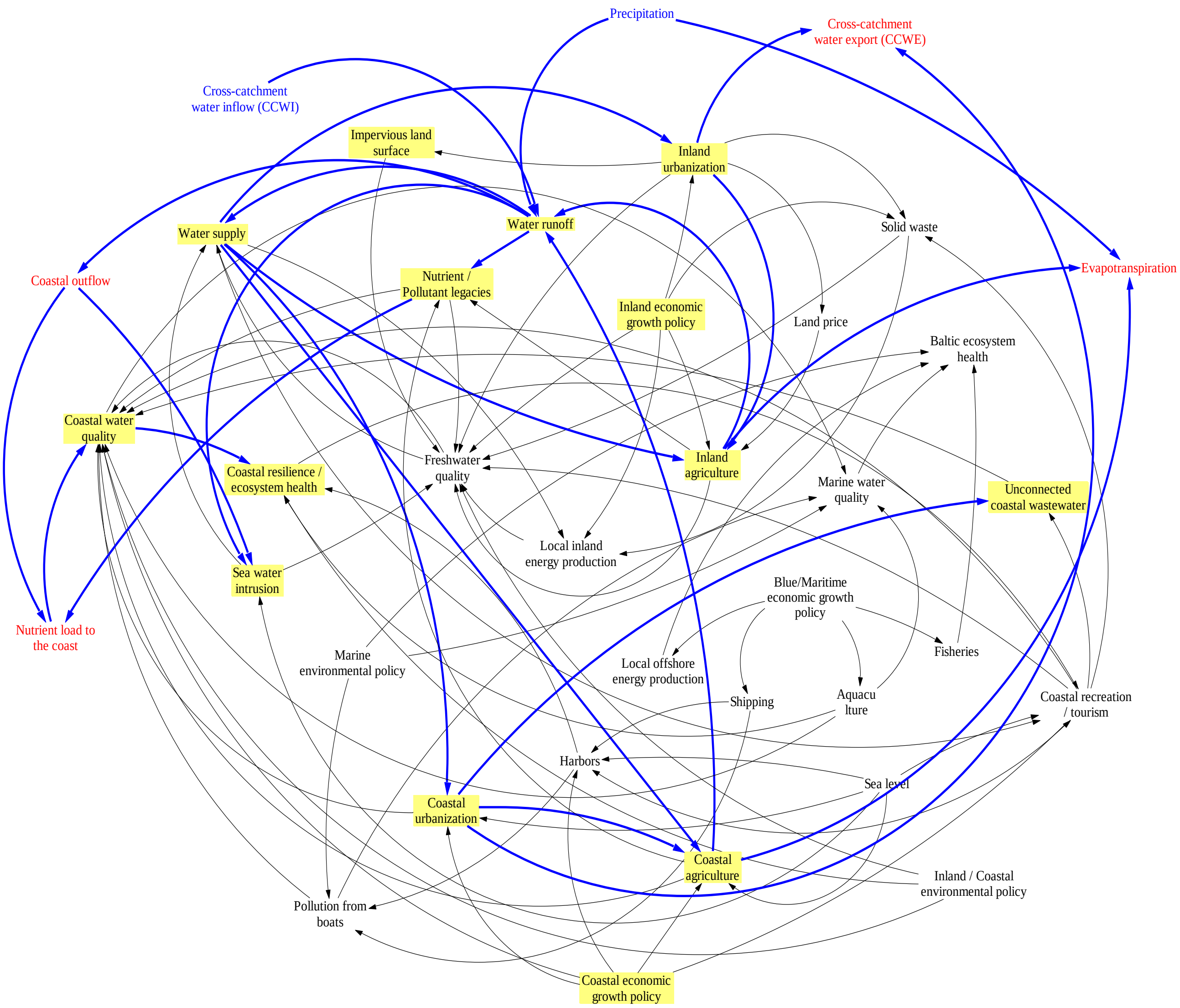


*Figure 50: Regional causal loop diagram (CLD) for MAL3. System components/sectors and interactions/implications selected for system dynamics (SD) modelling are highlighted with yellow background and thick blue arrows, respectively. System components shown with blue and red font colours along with their relevant interactions with the CLD components are added in order to close the loop between resources (shown in blue) and outputs (shown in red) in the MAL3 coastal system.*

Considering data and model (result) availability, two key topics have been identified as both robustly quantifiable and highly relevant to MAL3 problems in need for solution, and are explored further through focused fully quantitative SD modelling:

i. Cross-(sub)system/sector water availability exchanges (quantity perspective), and their implications for seawater intrusion into and quality of fresh coastal groundwater (quantity and quality perspective); and
ii. Cross-(sub)system/sector exchanges of waterborne nutrients and their loads through the catchment and towards and finally into the coastal waters (quality perspective).

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Two distinct, coherently related SD sub-models are developed to address and quantify these topics, for which the implications of various hydro-climatic change and economic development scenarios will be investigated for the coastal MAL3 region. In Figure 50, system components/sectors included in the SD sub-models for these two key topics are highlighted with yellow background and their associated interactions are identified with thick blue arrows. Complementary system elements and relevant interactions, which had to be distinguished in more detail and added as such to the CLD in order to address these topics, are shown with blue/red font colour, specifically regarding key external water flow inputs/outputs for the system (precipitation and cross-catchment water inflow (CCWI) in blue, evapotranspiration, cross-catchment water export (CCWE), water runoff and nutrient loading to the coast in red). They have been added to the CLD as needed for the SD modelling in order to determine relevant, realistic initial and boundary conditions and be able to close fundamental mass balances in the system.

The regional CLD in MAL3 (as shown in Figure 50) can be used to guide and focus on three types of system quantification and modelling with different levels of mechanistic basis and detail (Figure 51):

i. Semi-quantitative fuzzy cognitive modelling based on the whole CLD (as it was applied as part of WP1). The quantification process in the fuzzy cognitive modelling identified the direction of interactions within the CLD (as positive or negative relations) and assigned a fuzzy weight in the range of [0, 1] to the interactions representing the strength of their impacts.

ii. Quantitative mechanistic modelling to evaluate specific land-coast-marine processes, interactions and scenarios with mechanistic physical basis and detail (as done in some WP2 modelling for MAL3, and in supporting work of other research projects). With real data basis used to quantify system components, interactions and boundary conditions, this type of supporting modelling focuses on some key parts of the CLD (not the whole) with relatively high level of physical process basis and mechanistic detail.

iii. Quantitative SD modelling to address an extended system of CLD system components and interactions, possible to quantify robustly with less mechanistic process focus and detail, relative to those in model type ii. Both the fuzzy cognitive and the mechanistic modelling, as well as the stakeholder-given CLD for MAL3 support the structure, quantification and scenario analysis choices made and issues addressed in the SD modelling, using water quantity and quality evolution and changes for various relevant system development scenarios as tracer and basis for evaluating key land-coast-sea interactions and synergy opportunities.

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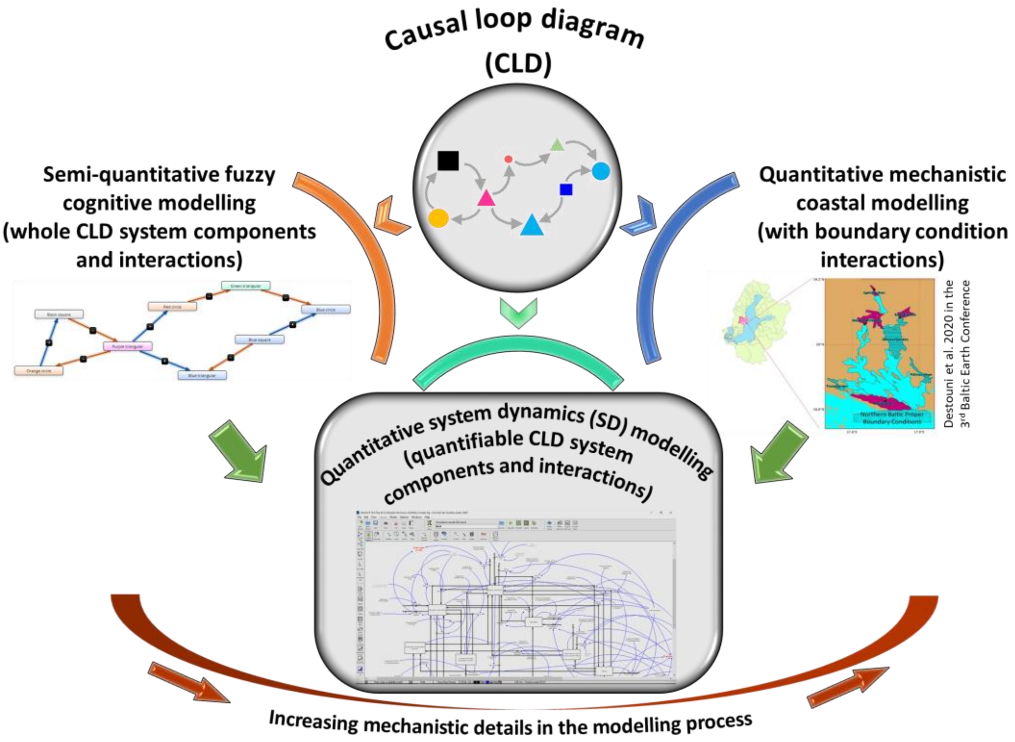


*Figure 51: Different types of quantification and modelling practices based on the unified stakeholder-given causal loop diagram (CLD) in MAL3.*

Different modelling approaches in combination can thus be applied to quantify land-sea interactions based on the unified CLD. As part of WP4, the focus in MAL3 has been on the SD modelling shown in the black box at the bottom of Figure 3.3.4. The SD model for MAL3 has been structured based on the CLD and the insights gained from fuzzy cognitive mapping (as part of WP1). It has been and further will be quantified and analysed through model scenarios with a significant support from data and model inventory that is developed as part of WP2 for MAL3 and includes reported quantitative information and peer-reviewed published outcomes of mechanistic land-coast-sea modelling in relevant scientific literature for MAL3.

Here, the SD modelling approach and its quantification, as developed for MAL3, is described in two parts associated with the two identified key topics relevant to the main problems (outlines in section 3.3.2 From multi actor analysis to modelling). In developing the two SD sub-models for these topics, fundamental physical mass balance is considered as a general key constraining condition for the land-sea water and waterborne nutrient interactions and impacts on various natural systems and socio-economic sectors, with focus on annual average conditions and their possible changes in different investigated scenarios of relevance for MAL3 system; long-term average conditions to current time are then considered as initial conditions in the SD modelling. Boundary conditions are given as recent-current average conditions and their possible shifts under different investigated change scenarios of input water flows (mainly precipitation and its mass-balance constrained - and, for recent-current conditions, data-given - partitioning to various sub-systems and sectors) and associated nutrient concentrations at the land surface and other main component boundaries in the representative MAL3 coastal hydrological catchment. To investigate main interaction and system shifts from recent-current annual average conditions to those of the various investigated change scenarios, the model simulations are based on annual time steps and the total simulation period is commonly considered as 100 years starting from recent-current conditions, considered around year 2010.

### 3.3.3. Pilot model 1 design: Land-sea inter-sectoral and coastal water exchange

#### *3.3.3.1. Model scope of the land-sea inter-sectoral and coastal water exchange*

The scope of sub-model 1 was determined based on the fact that water is an essential substance for sustainable development in every region and can be used for evaluation of many relevant inter-sectoral interactions. Sub-model 1 with the topic of land-sea inter-sectoral and coastal water exchange, investigates inland sectoral and coastal system interactions with regard to water flux and availability through natural surface and subsurface water systems. It also focuses on implications of the inland seaward flows and its changes due to hydro-climatic changes and inland and coastal human activities (e.g., urbanization, tourism, agriculture) for seawater intrusion risks in the MAL3 coastal region. As a result of increased human water use over the last century, the interactions between the natural water cycle and man-made water supply/handling systems also increase and their feedback to inland and coastal sectors in turn affect economic growth in the region (Baresel and Destouni, 2005). In addition, the pattern of water extraction from coastal aquifers directly affects the natural pattern of seawater intrusion. With significant impacts of hydro-climatic changes on groundwater levels and seaward flows, associated alterations can threaten large-scale contamination of the coastal groundwater resources (Mazi et al., 2016).

Figure 3.3.5 shows the conceptual structure of sub-model 1, based on/including the highlighted parts in the unified regional CLD for MAL3 in Figure 3.3.3. The main inputs to this sub-model are precipitation and CCWI (highlighted with blue font colour in Figure 3.3.5) feeding natural water resources (highlighted with green background in Figure 3.3.5) and supplying sectoral water uses (highlighted with grey background in Figure 3.3.5). These inputs (additional system components) are added to the conceptual structure of the sub-model 1 driven from the CLD to be able to close the loop between water resources, water consumers, and system outputs, to define boundary conditions in the sub-model 1, as well as to account for sectoral contributions to coastal water outflows. More/less freshwater runoff to the coast makes the seawater intrusion interface move less/more toward hinterland and thereby decreases/increases coastal groundwater salinity and costs for desalination. Therefore, seawater intrusion risks in sub-model 1 are evaluated based on the diffuse coastal discharge of subsurface water and its changes due to hydro-climatic changes (primarily represented by changes in precipitation, with associated evapotranspiration and inter-catchment fluxes, in Figure 52) and inland/coastal human activities. The main outputs of this sub-model are the fluxes of evapotranspiration, CCWE, water outflow to the coast, and a proxy of critical seawater intrusion risk (highlighted with red font colour in Figure 52).

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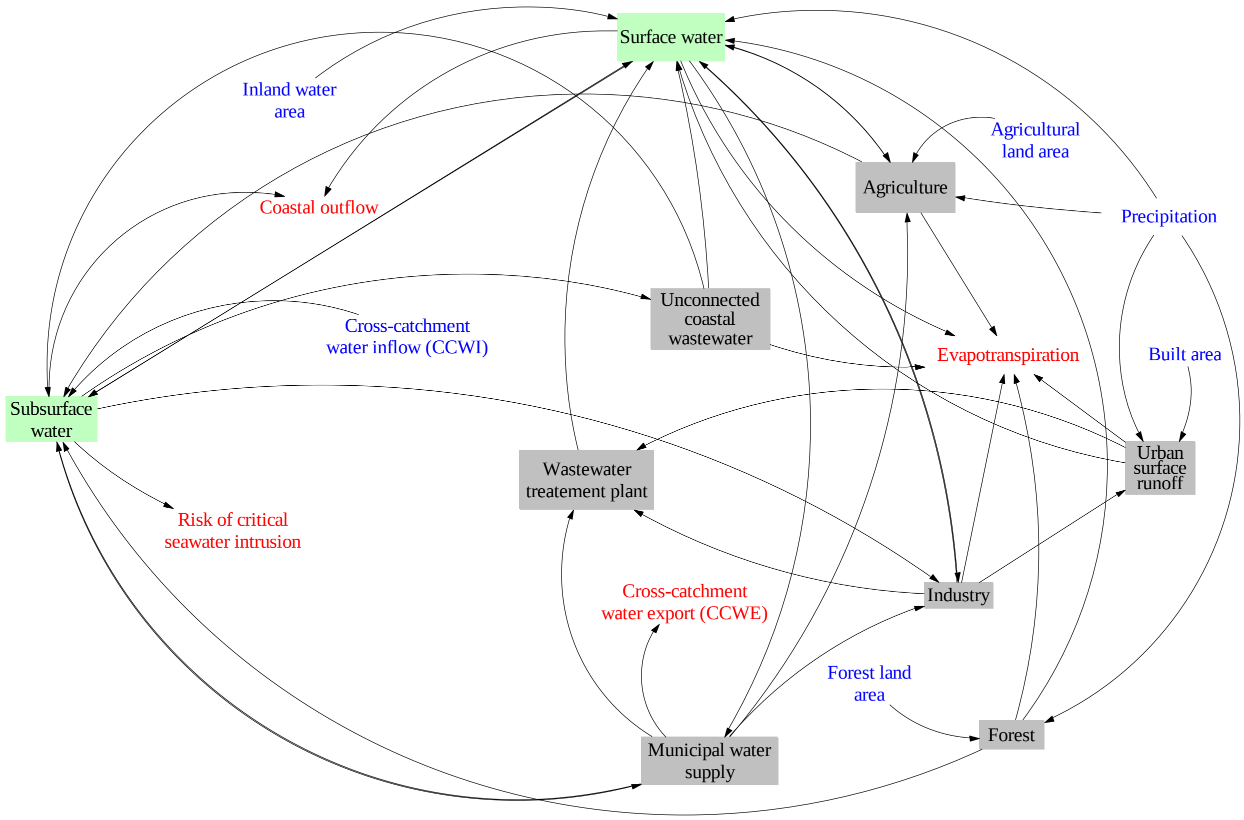


*Figure 52: Conceptual representation for sub-model 1 in MAL3 including water flux exchanges (represented by arrows) between natural water systems (highlighted with green background) and socio-economic inland/coastal sectors (highlighted with grey background). The diagram also includes sub-model inputs (identified with blue font colour) and outputs (identified with red font colour).*

#### 3.3.3.2. Quantification of the Land-sea inter-sectoral and coastal water exchange

Published peer-reviewed outcomes of an integrated input-output analysis (IOA) specifically for recent-current conditions in MAL3 (Baresel and Destouni, 2005; Cseh, 2009) are used to quantify inputs to sub-model 1 based on interactions between natural water systems and socio-economic inland/coastal sectors. Natural water systems (highlighted with green background in Figure 52) and inland/coastal sectors (highlighted with grey background in in Figure 52) are considered as stock variables. They collect available water at each time step from other systems/sectors that feed into them and use the collected water to supply inland/coastal sectors and interlink water exchange with other stock variables within the system. Therefore, their value shows the total system/sector water accumulation at each time step. The value of stocks is defined based on their connected inflow and outflow rate variables as:

$$Stock_t = Stock_{t-1} + dt \cdot \sum_{i=1}^{n} Inflow_{i,t} - dt \cdot \sum_{j=1}^{m} Outflow_{j,t} \qquad \begin{matrix} t = 2, 3, 4, \ldots, 100 \\ Stock_1 = Stock_{initial} \end{matrix} \tag{3.1}$$

where, $Stock_t$ and $Stock_{t-1}$ are the values of the stock respectively at time $t$ and $t-1$ (previous time step) (million m$^3$), $Stock_1$ is the value of the stock at the first time step which is an input to the model given by the user as $Stock_{initial}$ (million m$^3$), $Inflow_{i,t}$ is the inflow rate from stock/system/sector $i$ at time $t$ (million m$^3$/year), $Outflow_{j,t}$ is the outflow rate to stock/system/sector $j$ at time $t$ (million m$^3$/year), $dt$ is selected time step for the model as one year, $n$ and $m$ are the total number of

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stocks/systems/sectors that deliver and take water from the specific stock, respectively. Figure 53 exemplifies the stock variable of subsurface water and its inflow and outflow rates in sub-model 1. In this figure, as an example, $n$ is equal to 6, as the total number of inflow rates (connections) from surface water (SW) (natural water system), MWS, forest, agriculture, and unconnected coastal wastewater (UCWW) (inland/coastal sectors), and CCWI (natural water system input to the catchment). Also, for this stock variable, $m = 5$, as the total number of outflow rates (connections) to surface water (SW) (natural water system), industry, MWS, and UCWW (inland/coastal sectors), and outflow to the coast (natural water (sub)system output from the whole catchment).

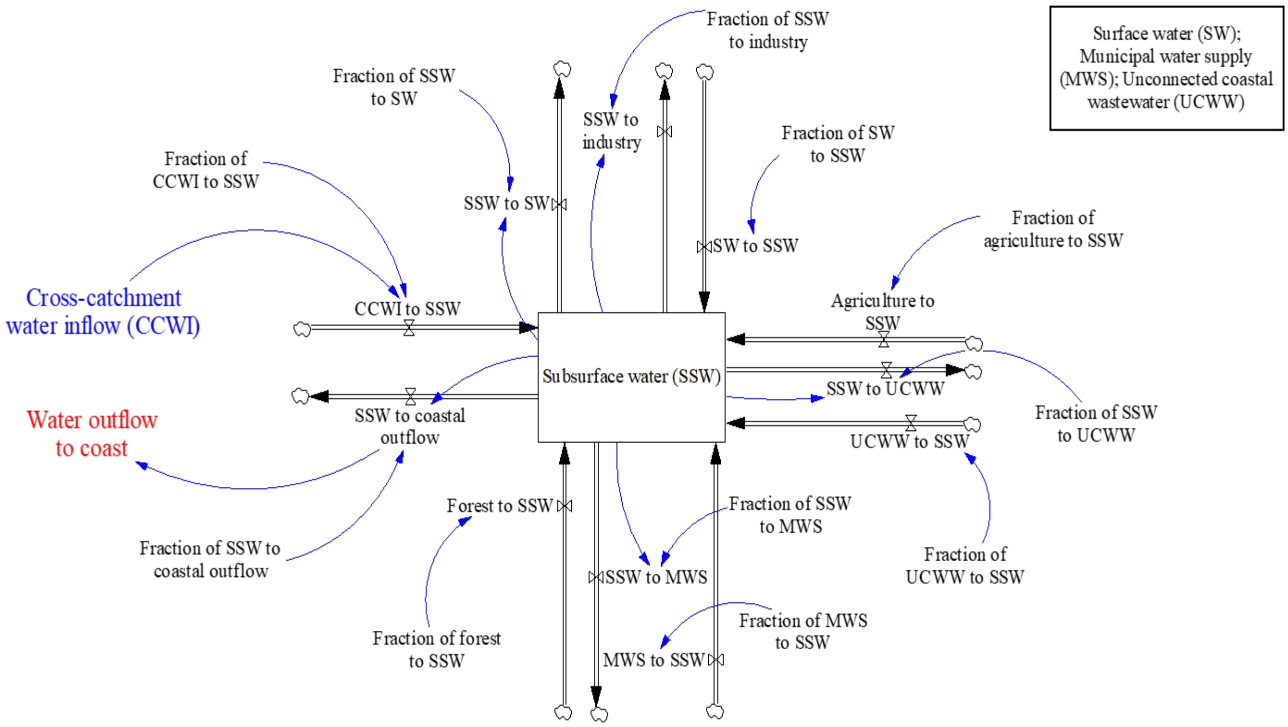


*Figure 53: Stock variable of subsurface water with its inflow and outflow rate variables in sub-model 1 for MAL3.*

Outflow rates from a stock are quantified as a fraction per time step of the value of that stock at the beginning of each time step as:

$$Outflow_t = Fraction \times Stock_t \qquad t = 1, 2, 3, \ldots, 100 \qquad (3.2)$$

where, $Fraction$ is an auxiliary variable with a constant value in the range of [0, 1] for all time steps (1/year). For the example of subsurface water stock (Figure 53), there is a specific $Fraction$ (auxiliary variable) connected to each inflow/outflow rate. Outflow rates from the subsurface water stock are defined based on the value of this stock and the relevant connected $Fraction$ variables. Inflow rates to the subsurface water stock are defined based on the value of their relevant stock variables and a $Fraction$ as in Equation 3.2.

In sub-model 1, outflow rates from a stock can be inflow rates to another stock (e.g., the outflow rate of “SSW to SW” from subsurface water stock in Figure 53 that is an inflow rate to surface water stock), or can contribute to model outputs (e.g., the outflow rate of “SSW to coastal outflow” from

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subsurface water stock in Figure 53 that contributes to total "Water outflow to coast"). Also, inflow rates to a stock can be outflow rates from another stock (e.g., the inflow rate of "Agriculture to SSW" to subsurface water stock in Figure 53 that is an outflow rate from agriculture stock), or can be quantified based on model inputs (e.g., the inflow rate of "CCWI to SSW" to subsurface water stock in Figure 53 that is defined based on system input of "Cross-catchment water inflow (CCWI)"). In conclusion, the multiplication structure defined in Equation 3.2 is applied to quantify the values of inflow and outflow rates for different stocks in sub-model 1 for MAL3.

Values of the $Fraction$ variables are determined based on a matrix table developed for recent-current conditions from the published results of an integrated IOA for the MAL3 region (Baresel and Destouni, 2005; Cseh, 2009). The matrix identifies average annual total water flux from each natural water system and inland/coastal sector and its partitioning among other systems/sectors. The values of $Fraction$ variables for outflow rates from a stock in sub-model 1 are calculated based on the partitioned water flux to other connected stocks; this partitioning can change with time, but is in our main scenario simulations, for simplicity, kept constant in each model scenario over the simulation time period (100 years starting from 2010), but varies to different degrees among scenarios.

Seawater intrusion risk in sub-model 1 is quantified based on the results of a published peer-reviewed modelling approach to seawater intrusion into coastal groundwater (Mazi et al., 2016) and to associated subsurface flow-related critical thresholds/tipping points (Mazi et al., 2013 and 2014). Recharge rate $r$ of coastal groundwater ($Q_{in}$ in Figure 49, determined by precipitation ($P$) minus evapotranspiration ($ET$)), the fresh groundwater flow to the coast (fresh submarine groundwater discharge, $Q_{SDG}$, in Figure 54) is then determined as:

$$Q_{SDG} = r \times A_{lw} \tag{3.3}$$

where $A_{lw}$ is the coastal catchment area down-gradient of the average location of wells withdrawing coastal groundwater at rate $Q_w$ (at some average normal distance $lw$ from the coastline, Figure 54).

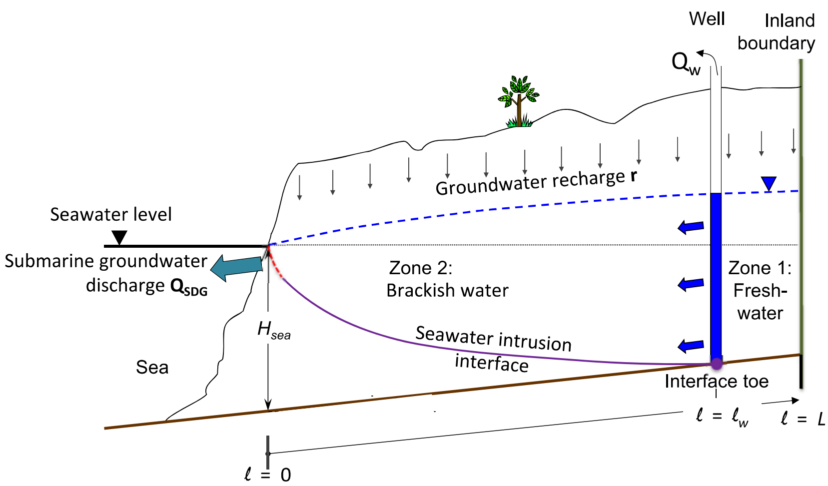


*Figure 54: Schematic of seawater intrusion into coastal groundwater (modified version of Figure 1a in Mazi et al., 2016).*

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Zero pumping, $Q_w = 0$, implies $A_{lw} = A_L$ where $A_L$ is the maximum catchment area of the coastal groundwater, as determined by the coastal ground water divide located at normal distance $L$ from the coastline (Figure 54). To avoid critical seawater intrusion into wells, the maximum allowable pumping rate is:

$$Q_{w-max} = r \times (A_L - A_{lw}) \quad (3.4)$$

For any given coastal groundwater catchment area $A_L$, and with maintained pumping locations and thus $A_{lw}$, a change in the modeled subsurface water flow to coast (illustrated in Figure 53) from a base condition of $Q_{SDG1}$ to another condition of $Q_{SDG2}$ implies that:

$$\frac{Q_{w-max2}}{Q_{w-max1}} = \frac{r_2}{r_1} = \frac{Q_{SDG2}}{Q_{SDG1}} \quad (3.5)$$

If $Q_{SDG}$ changes due to change in $A_{lw}$ (e.g., due to changed coastal tourism/recreation or urban conditions requiring more or less pumping ($Q_w$) with rate $r$), then:

$$\frac{A_{lw2}}{A_{lw1}} = \frac{Q_{SDG2}}{Q_{SDG1}} \quad (3.6)$$

In either case, $\frac{Q_{SDG2}}{Q_{SDG1}} < 1$ ($> 1$) implies inland (seaward) movement of the seawater intrusion interface (Figure 54). Based on the above, a relevant proxy, with change sign consistency in quantification of increased (decreased) risk of critical seawater intrusion, can be further used to quantify seawater intrusion risk as:

$$1 - \frac{Q_{SDG2}}{Q_{SDG1}} \quad (3.7)$$

Specifically, positive (negative) values of Equation 3.7 indicate decrease (increase) of $Q_{SDG2}$ compared to $Q_{SDG1}$, and thereby increased (decreased) risk of critical seawater intrusion into the regional coastal groundwater resource. Equation 3.7 is used to quantify proxy of seawater intrusion risk in sub-model 1 where $Q_{SDG1}$ is considered as the amount of subsurface water flow to the coast for the base case that is quantified as multiplication of a constant fraction and the initial value of the subsurface water stock in this sub-model (Equation 3.2).

Inputs to sub-model 1, such as precipitation and CCWI, are considered as auxiliary variables (as shown as an example in Figure 53), and their values for recent-current conditions are determined based on the published results of the integrated IOA for MAL3 (Baresel and Destouni, 2005; Cseh, 2009). Their values are further partitioned among connected systems/sectors (stocks in the model) receiving water input fractions from these total catchment water inputs (based on Figure 52). Sub-model outputs, such as evapotranspiration, CCWE, water outflow to coast, and proxy of seawater intrusion risk, are also considered as auxiliary variables (as shown as an example in Figure 53), and their values are calculated based on the modelled system/sector interactions in sub-model 1 (shown in Figure 52). The overall stock-flow structure of the SD sub-model 1 for MAL3 is presented in Figure 55 developed based on the conceptual structure (Figure 52) and the explained quantification approach in this section.

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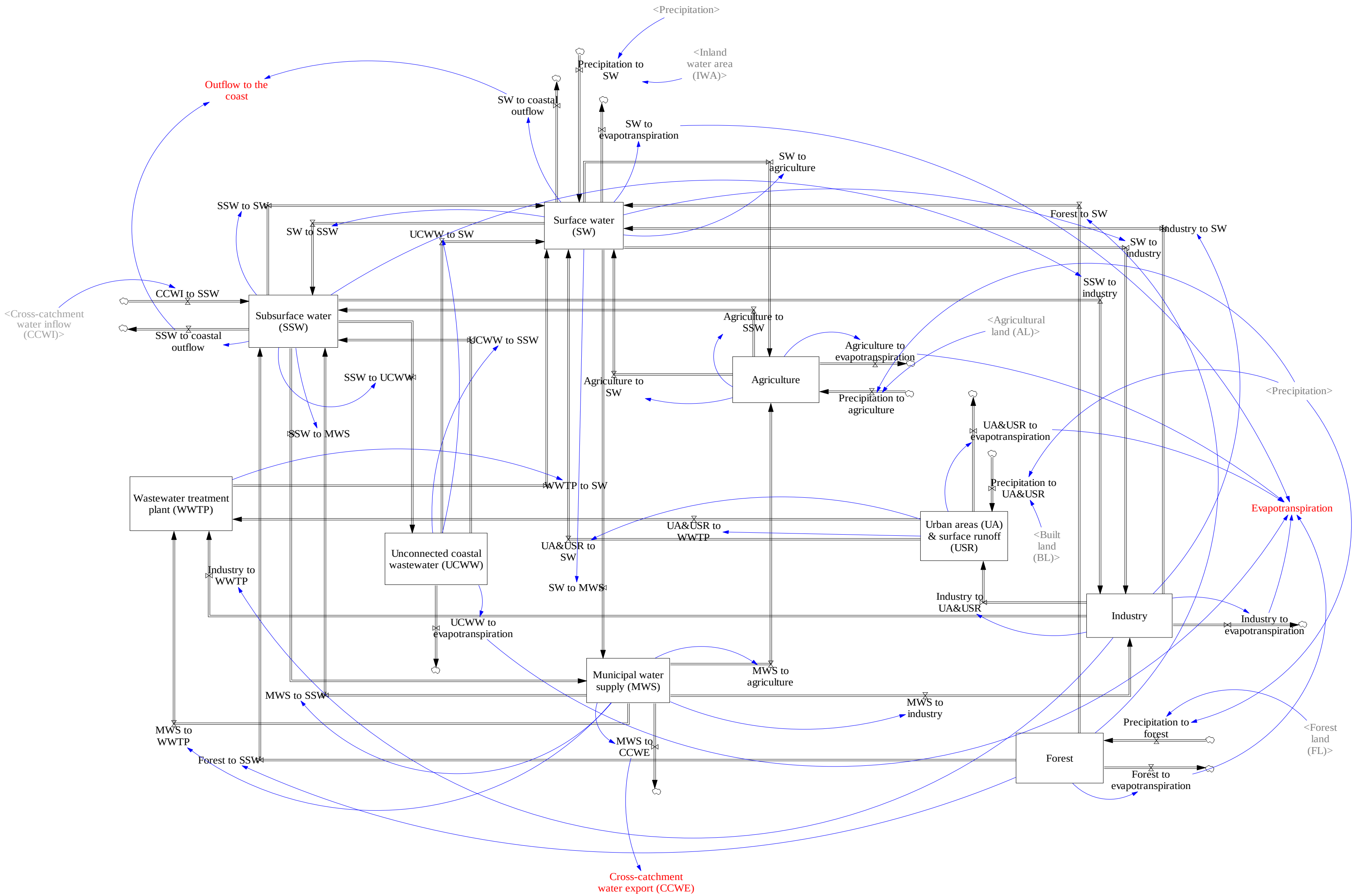


*Figure 55: Stock-flow structure of the SD sub-model 1 for MAL3 developed in Vensim software. The main outputs of the model are shown with red font color.*

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### 3.3.4. Pilot model 2 design: Land-sea inter-sectoral and coastal waterborne nutrient exchange

#### *3.3.4.1 Model scope of the land-sea inter-sectoral and coastal waterborne nutrient exchange*

Sub-model 2 for MAL3 is used to investigate contributions of different inland/coastal sectors to waterborne nutrient loads through surface and subsurface inland waters to the coastal waters. Main nutrient loads for coastal eutrophication are predominantly waterborne from land and their changes are closely related to water flow changes, e.g., due to hydro-climatic changes and/or inland/coastal sector developments. In general, including in MAL3, subsurface water may play an important role in coastal waterborne nutrient loading due to subsurface accumulation and delayed release and transport of nutrients as legacy sources (Baresel and Destouni, 2006; Lindgren et al., 2007; Darracq et al., 2008; Basu et al., 2010; Destouni and Jarsjö, 2018), resulting in higher nutrient concentrations in subsurface water than in surface water flowing to the coast (Destouni et al., 2008). With nutrient load development largely controlled by such delayed load contributions from subsurface legacy sources, regional nutrient loads to inland and coastal waters are likely to change in the future as a result of hydro-climatic and human activity changes shifting the water flows in and through the associated hydrological catchments (Destouni and Darracq, 2009; Bring et al., 2015; Destouni et al., 2017).

Sub-model 2 represents the relationships between sectoral water flows and nutrient exchanges given the above-described data-given concentration and load conditions and relationships with water flows. It can also be used to evaluate possible policy feedbacks from coastal nutrient loading to sectoral nutrient regulations, limiting their allowed nutrient exchanges, in associated development scenarios. The development of sub-model 2 is in progress and will be structured based on Figure 56 where nitrogen (N) and phosphorous (P) are the key nutrients considered for MAL3. Their average recent-current (possible future) concentration levels in surface and subsurface water as well as in WWTP exchange flows are data-given (scenario-formulated/assessed) model inputs (highlighted with blue font colour in Figure 56). Their connections to other system components follow the water exchange interlinkages between resources and water consumers as socio-economic inland/coastal sectors, since the focus will be on inter-sectoral waterborne nutrient exchanges. The main outputs of sub-model 2 are nutrient exchanges among different systems and sectors, leading to their contributions to nutrient loads to the coast through surface and subsurface waters and in total for MAL3.

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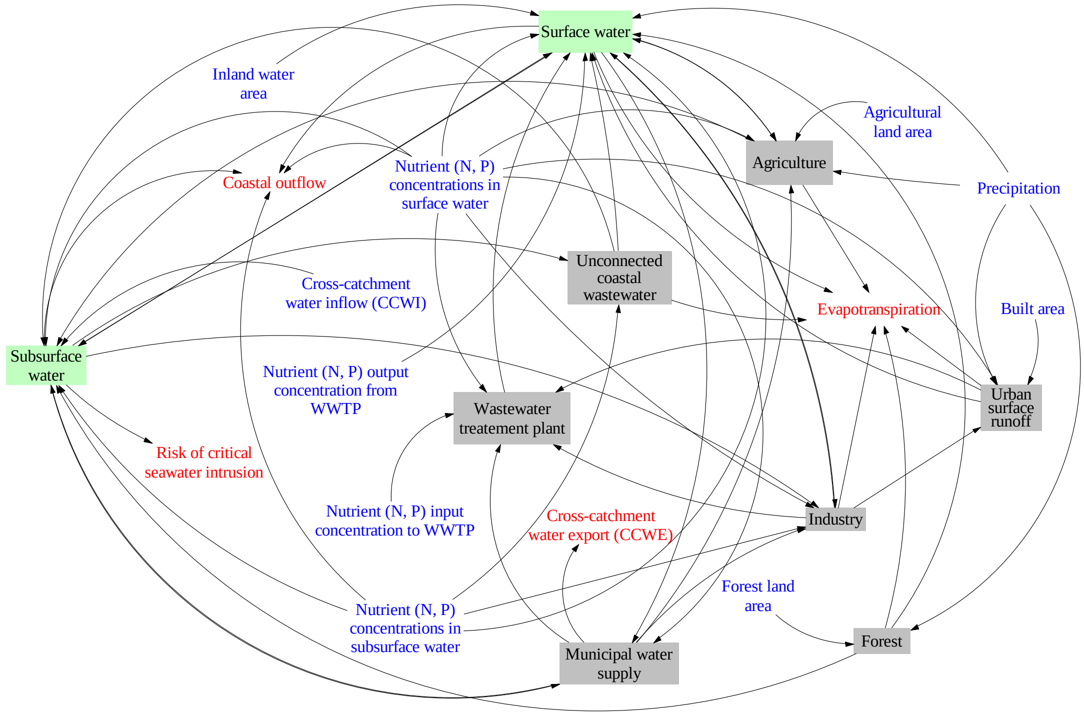


*Figure 56: Conceptual representation for sub-model 2 in MAL3 including nutrient exchanges (represented by arrows) between natural water systems (highlighted with green background) and inland/coastal sectors (highlighted with grey background). The general sub-model inputs and outputs are shown with blue and red font colour, respectively.*

#### 3.3.4.2 Quantification of the land-sea inter-sectoral and coastal waterborne nutrient exchange

Stock-flow structure development based on the conceptualization shown in Figure 56 for sub-model 2 requires nutrient (N and P) concentrations as inputs. Based on actual data-given, published and peer-reviewed nutrient concentration behaviour observed in MAL3 (Destouni and Jarsjö, 2018) and more generally over Sweden and the whole Baltic region and other parts of the world (Basu et al., 2010; Levi et al., 2018), as well as for multi-scenario analysis comparability and simplicity, average concentration levels are considered constant over time in each scenario, but vary between scenarios. Swedish nutrient concentrations in water flows from land to the Baltic Sea coast are primarily monitored in the stream networks (green areas in Figure 57) draining around 80% of total coastal catchment area on land (Hannerz and Destouni, 2006). With recent-current values of nutrient concentrations ($C$) (mg/lit) in surface waters given by monitored data, corresponding average nutrient loads $L$ (tonnes/year) are, by definition, determined as:

$$L = C \cdot Q \tag{3.8}$$

where $Q$ is annual average surface water discharge (million m$^3$/year), evaluated for the MAL3 catchment into the Baltic Proper marine basin (HELCOM, 2013b). As described above, these average concentration levels are relatively stable temporally or subject to only mild short-term variations and slow long-term changes, as assessed (e.g., Destouni et al., 2017; Destouni and Jarsjö, 2018) and considered (e.g., Bring et al., 2015) in multiple previous studies. They are also mechanistically shown to be maintained as such if the concentration contributions from diffuse subsurface legacy sources are dominant (Destouni and Jarsjö, 2018). Therefore, these stable average concentration levels are considered as inputs in sub-model 2.

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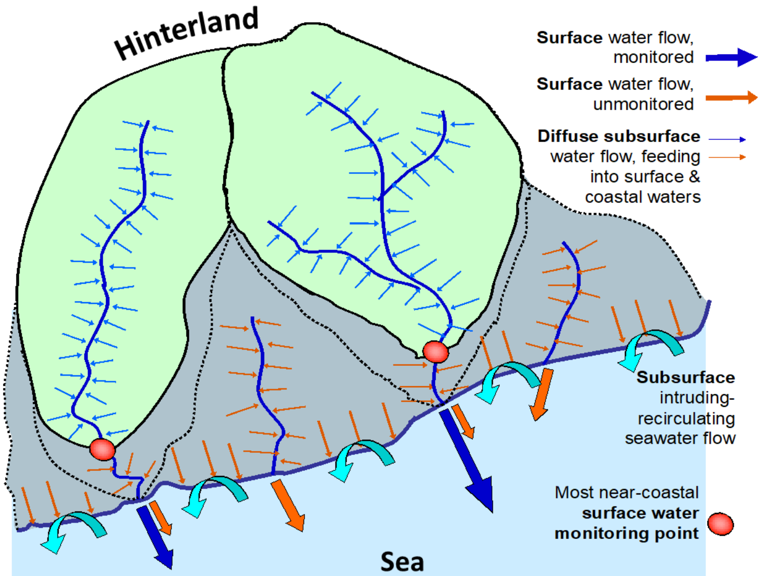


*Figure 57: Schematic of land to sea flows through the coast (modified version of Figure 2 in Destouni et al., 2008).*

The remaining, unmonitored 20% of the coastal catchment area include the parts located directly by the coast (grey areas in Figure 57) and mainly represent the diffuse subsurface flow contributions to coastal nutrient loads. In Sweden, these unmonitored parts contain 55% of the total Swedish population (Hannerz and Destouni, 2006). There is thus a fivefold higher population density in these unmonitored areas directly by the coast than in the more inland monitored areas. With this observed population density difference between the monitored and unmonitored catchment areas, and the data-given surface water concentration levels for the monitored surface water loads (based on Equations (3.3.8)), average nutrient concentrations in subsurface water can be estimated using mathematical techniques to modify the following linear regression relationships, found to apply between surface water nutrient concentration and population density at catchment scale in the Baltic region and other parts of the world (Levi et al., 2018):

$$C_N \approx 10.0324 \times pop + 0.4412 \qquad R^2 = 0.82 \qquad (3.9)$$

$$C_P \approx 0.0012 \times pop + 0.0238 \qquad R^2 = 0.90 \qquad (3.10)$$

In these relationships, $C_N$ and $C_P$ are surface water concentrations of total N and total P (mg/lit), respectively, and $pop$ is population density (population/km$^2$). The estimated average concentrations based on these data-based regression relationships are also considered as inputs to sub-model 2 for calculation of subsurface waterborne nutrient loads to the coast for the MAL3 case. As such, nutrient concentrations in subsurface water in the densely populated coastal areas are obtained as higher than the monitored values for the surface water flows in the whole MAL3 coastal areas, reflecting the commonly higher population density in coastal than in more inland land areas, as well as the influences of subsurface legacy sources that keep these concentrations at relatively constant levels over time.

Nutrient concentrations for WWTP exchanges can be further quantified according to national reporting by the Swedish Environmental Protection Agency (Naturvårdsverket, 2016). Input concentrations to WWTP from urban areas and surface runoff (UA&USR) are equal to observed surface water concentrations. Input nutrient concentrations from industry and MWS to WWTP can be quantified based on the reported removal efficiency and released concentrations from WWTP in the national report.

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Based on the data-given/derived nutrient concentration levels in surface and subsurface waters and inflows and discharges of WWTP, Equation 3.8 can be further used to quantify sectoral nutrient load exchanges ($L$) using the corresponding sectoral water flow exchanges ($Q$) from sub-model 1. As such, the two sub-models are connected through the water flow variables. Any change in these due to human activity developments and/or hydro-climatic changes will also affect corresponding nutrient exchanges among systems/sectors and their contribution to coastal nutrient loading. In sub-model 2, nutrient (N and P) concentrations are general inputs for data-based recent-current conditions and their possible shifts considered comparatively for different sector/policy development scenarios, while nutrient loads are the associated general outputs quantified based on Equation 3.8 for different scenario considerations.

### 3.3.5. Overview of the stock-flow models and land sea interactions

The overall CLD for MAL3 is shown in Figure 50 with relevant land-sea interactions considered in the two sub-models highlighted with blue arrows. The selected, focused and more limited consideration in fully quantitative SD modelling, is highlighted and separately shown in the simplified structures for each SD sub-model described in the previous sections. The two sub-models are combined to form the complete SD model for MAL3. For clarity and facilitated editing the two sub-models and their various components are assigned to different views in the Vensim software. The sub-model connection is explained and clarified in section 3.3.3.2.2 Quantification of sub-model 2. Based on multiple types of relevant available data and models and their results for MAL3, water flows among natural (sub)systems and inland/coastal socio-economic sectors are used as tracers in SD modelling to address following possible change and intervention scenarios and their impacts on land-sea interactions in MAL3:

- Climate projections showing average precipitation increases in the coming decades, which will affect annual renewable water availability for (supply and exchanges among) MAL3 systems/sectors, as well as seaward freshwater flows. In addition, sea level rise as one of the main challenges for coastal regions along with increased pressures on coastal aquifers due to human activity developments on land, which may lead to higher seawater intrusion risks in the future.
- Developments in inland and coastal human activities (e.g., tourism, agriculture, urbanization and industry) affecting waterborne nutrient loading to the coast, as well as nutrient deliveries and exchanges among different inland/coastal sectors. Associated nutrient load changes will then depend on nutrient concentrations, which may vary between and according to considered change scenarios, as well as on associated changes in inter-system/sectoral water exchanges.

### 3.3.6. Problems that can be addressed with the SD models

In further detail, the developed SD sub-models for MAL3 will be used to address and test following types of change scenarios and associated land-sea interaction and environmental changes:

- **Hydro-climatic change and its impacts** on renewable water resources for sectoral activities on land and coastal hinterlands;
- **Inland/coastal green sector (i.e., agriculture and forestry) developments/changes** and associated impacts on sectoral land shares, freshwater quantity and quality as well as coastal water quality;
- **Inland/coastal urbanization (i.e., urban areas, water supply infrastructures and industry)** and its impacts on sectoral land shares, freshwater quantity and quality, as well as coastal water quality;

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- **Combined impacts of changes mentioned above** (the three previous points) on sectoral land shares, freshwater quantity and quality, as well as coastal water quality;
- **National and international environmental regulations and agreements** (e.g., Water Framework Directive (WFD), Maritime Spatial Planning (MSP), and the Baltic Sea Action Plan (BSAP)) in relation to nutrient loading to coastal waters and the Baltic Sea and associated feedbacks to inland and coastal economic activities.

The water flows through and among natural water systems and inland/coastal sectors, and to the coast, evapotranspiration and water exports from the catchment, the proxy of seawater intrusion risk, the inter-system/sectoral nutrient (N and P) exchanges, and the coastal nutrient loads will overall be addressed/modelled by the related SD sub-models with annual time steps over a total time scale of multiple decades up to a century perspective.

### 3.3.7. Main model variables

The main variables that are used in the two SD sub-models for MAL3 are listed in Table 3 and Table 4 for sub-model 1 and 2, respectively.

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*Table 3: Main variables in the SD sub-model 1 for MAL3 (I: input, O: indicator, S: stock, F: flow, A: auxiliary, SW: surface water, SSW: subsurface water, MWS: municipal water supply, UCWW: unconnected coastal wastewater, UA&USR: urban areas and surface runoff, WWTP: wastewater treatment plant, CCWI: cross-catchment water inflow, CCWE: cross-catchment water export)*

| Topic | Name | Unit | Role | SD | Definition |
|---|---|---|---|---|---|
| **Catchment definition** | Total catchment area | $m^2$ | I | A | Total or representative inland catchment of considered coastline |
| **Water area** | SW area | $m^2$ | I | A | SW area within catchment |
| **Land area** | Agricultural land area | $m^2$ | I | A | Agricultural area within catchment |
| **Land area** | Forest land area | $m^2$ | I | A | Forest area within catchment |
| **Land area** | Built land area | $m^2$ | I | A | Urban built area within catchment |
| **Land area** | Other areas | $m^2$ | I | A | Land area without built, agriculture, forest and water cover within catchment |
| **Water input** | Precipitation | m/year | I | A | Long-term average precipitation over catchment |
| **Water input** | CCWI to SSW | Million $m^3$/year | I | F | Additional long-term average net groundwater inflow from adjacent basins (CCWI) to the catchment SSW |
| **Water input partitioning** | Precipitation to SW | Million $m^3$/year | I | F | Annual water input flux from precipitation to SW – proportional to relative SW area |
| **Green water output** | Evapotranspiration | Million $m^3$/year | O | A | Total annual evapotranspiration |
| **Green-blue water output partitioning** | SW to evapotranspiration | Million $m^3$/year | O | F | Annual water output flux by evaporation from SW – proportional to relative SW area |
| **Inter-system/ sector water flow exchanges** | Flows between natural water systems and inland/coastal sectors | Million $m^3$/year | O | F | Exchange (factor) matrix for annual water flows among SW and SSW as natural water systems, and agriculture, forest, UA&USR, industry, MWS, UCWW and WWTP sectors |
| **Main system/ sector water availability** | SW | Million $m^3$ | O | S | Total annual SW availability (including also sector return flows to SW) |
| **Main system/ sector water availability** | SSW | Million $m^3$ | O | S | Total annual SSW availability (including also sector return flows to SSW) |
| **Main system/ sector water availability** | Agriculture | Million $m^3$ | O | S | Total annual water availability for agriculture (including also other sector return flows to agriculture) |
| **Main system/ sector water availability** | MWS | Million $m^3$ | O | S | Total annual water availability for MWS |
| **Main system/ sector water availability** | Industry | Million $m^3$ | O | S | Total annual water availability for industry (including also other sector return flows to industry) |
| **Blue water output** | Total water outflow to coast | Million $m^3$/year | O | A | Total annual water outflow to the coast |
| **Blue water output partitioning** | SW outflow to coast | Million $m^3$/year | O | F | Annual water flow to the coast through SW and riverine network |
| **Blue water output partitioning** | SSW outflow to coast | Million $m^3$/year | O | F | Annual water flow to the coast through SSW and subsurface flows |
| **Water output** | MWS to CCWE | Million $m^3$/year | O | F | Additional long-term average drinking water export from the catchment MWS |
| **Inland-coastal water interaction** | Proxy of seawater intrusion risk (SWIR) | Dmnl | O | A | Proxy of seawater intrusion risk for coastal groundwater – related to SSW outflow to coast |

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*Table 4: Main variables in the SD sub-model 2 for MAL3 (I: input, O: indicator, S: stock, F: flow, A: auxiliary, SW: surface water, SSW: subsurface water, MWS: municipal water supply, UCWW: unconnected coastal wastewater, UA&USR: urban areas and surface runoff, WWTP: wastewater treatment plant, CCWI: cross-catchment water inflow, CCWE: cross-catchment water export, P: phosphorous, N: nitrogen)*

| Topic | Name | Unit | Role | SD | Definition |
|---|---|---|---|---|---|
| **Water flows** | Water flows related to systems and sectors listed in this table | Million $m^3$/year | I | F | Various system-sector average annual water flows obtained from sub-model 1 |
| **Nutrient concentrations** | P and N concentrations in SW | kg/$m^3$ | I | A | Average phosphorous and nitrogen concentration levels in SW |
| **Nutrient concentrations** | P and N concentrations in SSW | kg/$m^3$ | I | A | Average phosphorous and nitrogen concentration levels in SSW |
| **Nutrient concentrations** | P and N concentrations in WWTP input flows | kg/$m^3$ | I | A | Average phosphorous and nitrogen concentration levels in input flows to WWTP |
| **Nutrient concentrations** | P and N concentrations in WWTP outputs | kg/$m^3$ | I | A | Average phosphorous and nitrogen concentration levels in discharges from WWTP into SW |
| **Nutrient loads** | P and N load exchanges among natural water systems and inland/coastal sectors | Thousand kg/year | O | A | Average annual phosphorous and nitrogen load exchanges among SW and SSW as natural water systems, and agriculture, forest, UA&USR, industry, MWS, UCWW and WWTP sectors |
| **Nutrient loads** | Total P and N loads to the coast | Thousand kg/year | O | A | Average annual phosphorous and nitrogen loads to the coast (through SW, SSW and both) |

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### 3.3.8. Data sources

Technical and scientific peer-reviewed publications and official reports are mainly considered for quantification of the two SD sub-models in MAL3. Some of them have already been listed in the data and model inventory for MAL3 as part of deliverable D06(D2.1) in WP2. Here, they have also been explicitly cited in the sections related to quantification of the two sub-models, and include primarily:

Baresel, C., and Destouni, G. (2005) Novel quantification of coupled natural and cross-sectoral water and nutrient/pollutant flows for environmental management.

Bring, A., Rogberg, P., and Destouni, G. (2015) Variability in climate change simulations affects needed long-term riverine nutrient reductions for the Baltic Sea.

Cseh, M. (2009) Multi-approach comparison of nutrient flow modeling in the Norrström drainage basin. Master thesis of Environmental Engineering.

Destouni, G., Hannerz, F., Prieto, C., Jarsjö, J., and Shibuo, Y. (2008) Small unmonitored near-coastal catchment areas yielding large mass loading to the sea.

Hannerz, F., and Destouni, G. (2006) Spatial characterization of the Baltic Sea Drainage Basin and its unmonitored catchments.

Helsinki Commission (HELCOM) (2013b) Review of the fifth Baltic Sea pollution load compilation for the 2013 HELOCM Ministerial Meeting.

Helsinki Commission (HELCOM) (2007) Baltic Sea Action Plan.

Levi, L., Cvetkovic, V., and Destouni, G. (2018) Data-driven analysis of nutrient inputs and transfers through nested catchments.

Mazi, K., Koussis, A.D., and Destouni, G. (2016) Quantifying a sustainable management space for human use of coastal groundwater under multiple change pressures.

Swedish Environmental Protection Agency (Naturvårdsverket) (2016) Wastewater treatment in Sweden 2016.

### 3.3.9. Planning

Next steps in structuring and quantifying the SD sub-models for MAL3 are summarized as:

- Completing the structure of and quantifying sub-model 2 for the land-sea waterborne nutrient exchanges;
- Testing model scenarios of climate change, green sector development and coastal urbanization (reflecting coastal tourism development), and assess their implications for land-sea system/sector interactions and possible associated policy and roadmap developments;
- Analysing model scenario results to evaluate their sensitivity to scenario assumptions and variations, identify the possible most positively impactful synergies between various land-coast-sea economic activities and policies for future coastal developments and environmental improvements, with particular focus on mitigating inland, coastal and Baltic Sea water pollution and eutrophication.

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

### 3.4.1 Problem scope of the land sea system

The part of the Charente River watershed (10000 km²) located upstream, downstream and beyond the coastal zone is under significant environmental pressure from different economic activities such as summer tourism, agriculture, and shellfish farming.

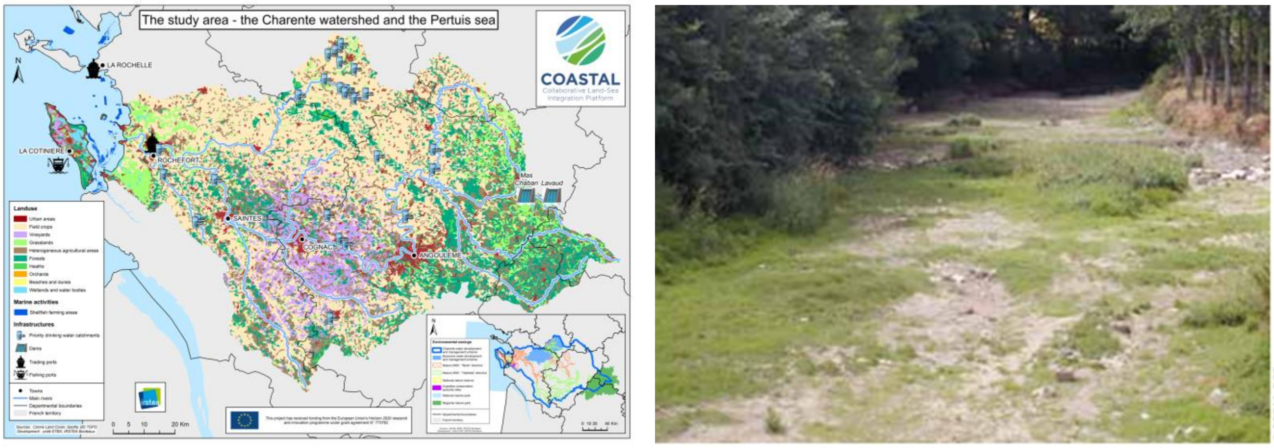


*Figure 58: The Charente river basin with illustration of the main concern of this MAL (one tributary of the Charente River in summer).*

Environmental issues are even more important as the urban coastal population is steadily increasing, resulting in continued pressure on land availability in rural areas, protected areas and the many salty or freshwater wetlands. The use of water resources for drinking water and irrigation, as well as for the preservation of a minimum instream flow to protect aquatic ecosystems requires large volumes of water. Water resources are limited, and this limitation is even enhanced by the effect of climate change (droughts in spring and summer)... This situation although quite common 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 by agriculture with irrigation of crops (mainly maize), use of nitrate (in particular with cereal crops) and pesticides (notably on vines used for Cognac production) and domestic use have a significant impact on water resources. Changes in farming systems and more sustainable practices are the only solution 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.

The preservation of coastal water quality (salinity, planktonic and benthic production) is of utmost importance for selfish farming and professional inshore fishing. In addition, due to the flatness of the coast, the presence of important wetlands increases the effects of climate change (sea level rise) and the possible soil salinization of 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

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in one part of the territory will impact employment in several sectors and location of the rural- and coastal zones.

The situation is further complicated due to the continuous increase of residential or immigrant 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 raise 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, maize), on which the activity of La Rochelle port largely depends. Opposes of reservoir development argue for the potential imbalance of the water cycle and the privatization of water resources as a public good. Another new opportunity likely to cause disruption is a shift from present farming systems towards more environmental friendly systems with less water-dependent 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, is only accessible by smaller vessels.

The main land-sea interactions in the coastal MAL3 region were identified through the sector workshops and the combined multi-actor workshop as part of WP1 in the COASTAL project around two main issues: water needs and land use availability and associated economic concerns.

. The land sea interactions we will consider in the model are:

- The dependence of downstream activities (primarily shellfish farming but also coastal tourism) on upstream activities (agriculture) in terms of water quantity and quality;
- Interactions between the development of coastal summer tourism the increase of the coastal population and the development of irrigated crops;
- Interactions between the development of cash crops in the hinterland and the development of trading port activities implying infrastructure investments;
- Interactions between the development of organic crops, the associated development of short supply chains or export of these products and infrastructure development (specific storage, economic support by regional authorities)
- Interactions between the changes of agricultural systems and the coastal water quality. (use of fertilizers and pesticides depending on the evolution of practices)

### 3.4.2 From Multi actor analysis to modelling

The key concerns discussed in the workshops were the following: impacts of climate change, population changes and concentration of economic 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 rise.

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 more severe droughts and potential intrusion of saline water.

Adaptations to address these concerns present opportunities to change production systems (particularly farming systems) and practices to make current activities more resilient.

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

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- **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 tourists and retirees favour coastal zones. This phenomenon causes an upsurge in land prices, a change in consumption behaviour, and demands for new services and infrastructure, unbalanced between coastal and rural areas...
- Summer tourism causes coastal congestion and leads to a growing demand for drinking water and needs for larger capacities for water treatment plants (already in high demand)..
- The development of ports relies on inland agricultural production and any change in farming systems may have large impact on port activities. If 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 (risks of coastal flooding competition for space), coastal farmland (increased soil salinity), and the need to develop adapted agriculture and tourism in these areas.

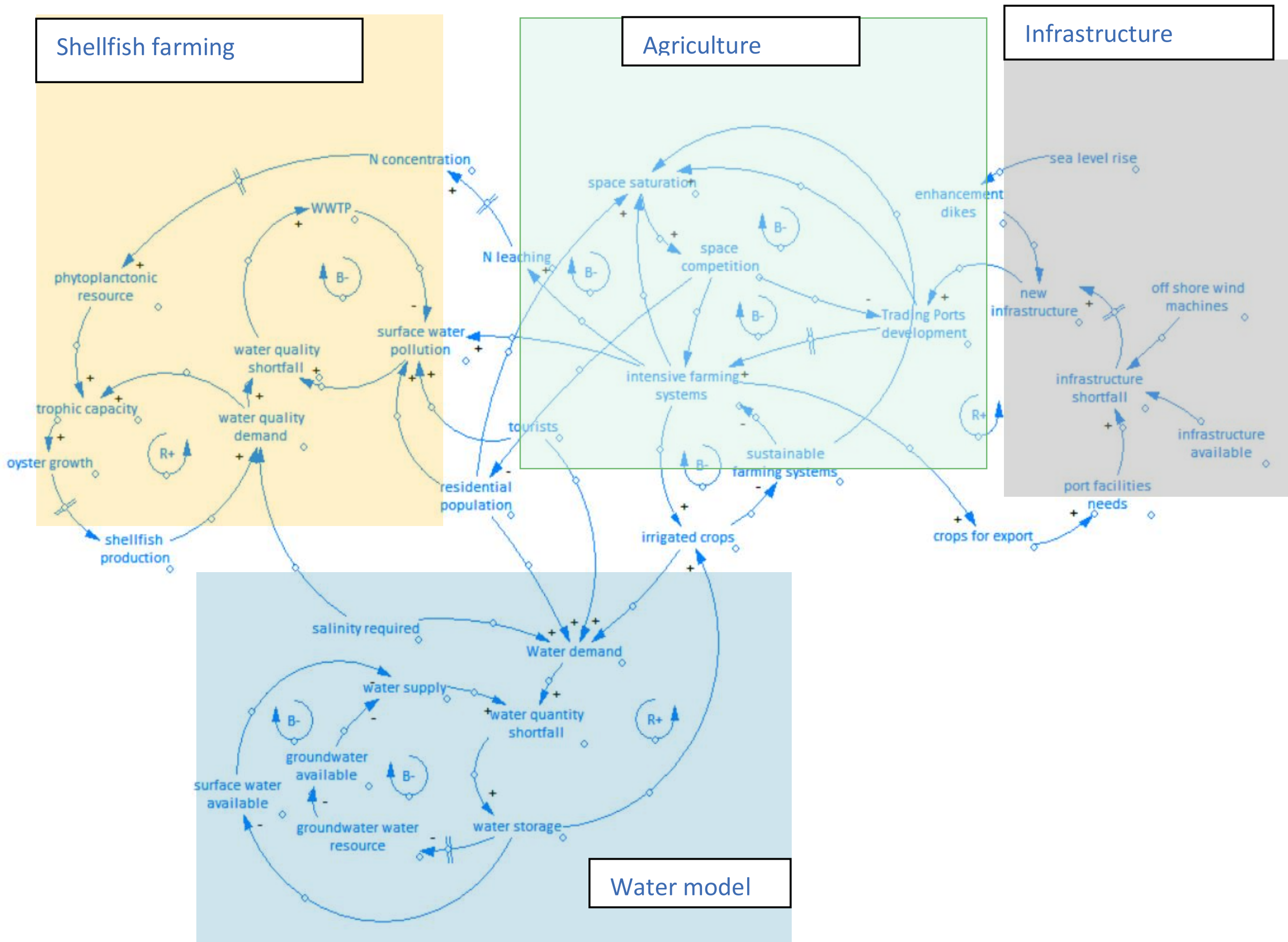


*Figure 59: Overview of the Causal Loop Diagram for the main land-sea interactions identified during the sector workshops with links to sector models.*

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The causal loop diagram of the land sea system was split into different stock flow (SF) sub-models considered relevant to tackle the main issues of the MAL4. More attention was however paid to the Water model because the water issue is the main concern for this case study. The CLD derived from sectorial workshops served as a basis for developing SF sub models. Some variables of the CLDs with similar meanings were merged and *some variables have been added when they happen to be needed for a better formalization of the links between variables*. All the variables of the causal loop diagrams were retained and defined as Level (or Stock) when they represented accumulations or depletions over time. When feedback loops were affected from outside the sub model, they were defined as constant (e.g. withdrawal authorization, instream flow requirements...). All other variables in the system were defined as Auxiliaries that were used or could be computed with the stocks and flows and are constants in the model. Some variables like climate change and its impact on air temperature increase and consequently evapotranspiration of crops were considered as exogenous variables affecting the water system but not affected by it.

Links between the water model and the agriculture model rely on water demand from crops, on the impact of farming systems on water quality (pesticide pressure indicator, Nitrogen pressure indicator and associated N fluxes,). Links between the shellfish production model and the water model rely on water quality, mortality frequency, oyster growth related to salinity required and Nitrogen concentration in coastal waters. Infrastructure is linked with the development of residential and tourist population and the development of trading ports with increase of export, development of storage for organic crops.

### 3.4.3 Overview of the stock-flow models and land sea interactions

#### *3.4.3.1 The water model*

##### *3.4.3.1.1 Model scope of the water model*

The objective of the water model is to propose a quantification of the interactions between the different rural and coastal human activities (tourism, shellfish farming, agriculture, infrastructure development), in an evolving economic and public policy context (concentration vs diversity), focusing on the interactions relating to the use of the water resource which is the main problem identified by the stakeholders.

To achieve this goal, we need to quantify relations between variables and convert the CLD addressing the water issues as identified with stakeholders into a SF model. Variables in the water model are of different types:

- Stochastic variables such as rain and temperatures (evapotranspiration), here exogenous variables;
- Delay variables (such as the recharge of groundwater, the runoff, surface and groundwater exchanges,) linked mainly to physical processes that have been included in the SF model;
- Adjustment variables intended to manage low-flows with long term adjustment variables like investments (construction of reservoirs, or increase of drinking water treatment plant capacity) and quick adjustment variables within the year for the managing of low-waters such as bans of irrigation for different lengths of time.

Other issues relate to the difficulty to assess state variables (Level variables in the SF model) such as groundwater stocks or surface water.

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#### *3.4.3.1.2 Quantification of the water model*

The water model was built in order to focus on the variability of water demand within years and between years, from the different water stocks that can be used to respond to water demand, taking into account the delays of physical variables and different scenarios of short-term and long-term management of low-water flows impacting economic activities mainly agriculture, shellfish farming and tourism. The need for sufficient fresh water of good quality as a main concern for shellfish farming is considered with the *Water in marshes* (Stock variable) and the *flow into the sea* (Flow variable) variables.  The controversial water reservoirs downstream have been taken into account as scenarios where possible increase of their capacity will be used to assess its impact on other activities. Agricultural water demand is a variable defined in the agricultural sub model that takes into account changes in farming systems implying crop rotation modifications including new crops that may not be irrigated. Tourist and population variables are also input variables to this model.

Upstream of the river Charente, there are two dams for releasing water to sustain low water flows. These are not far from each other and their capacity has been merged into a single Stock. The concepts of Low-Water Target Flow (DOE) and shortage management are included in the SF diagram with decision rules to represent how low-flow levels are managed within the year to limit water use. The time unit used in the model is then the month in order to highlighting the recurring problems of water shortage in summer and how this is managed.  The run is started for a time in the past. For the period in the past available measurement data will be used for validation of the model. The model is further run up to a time horizon of interest. In the case of climate change this could for example be up to 2100.  The time step has been chosen not too large (0.25) to prevent large overshoot and undershooting of the goal.

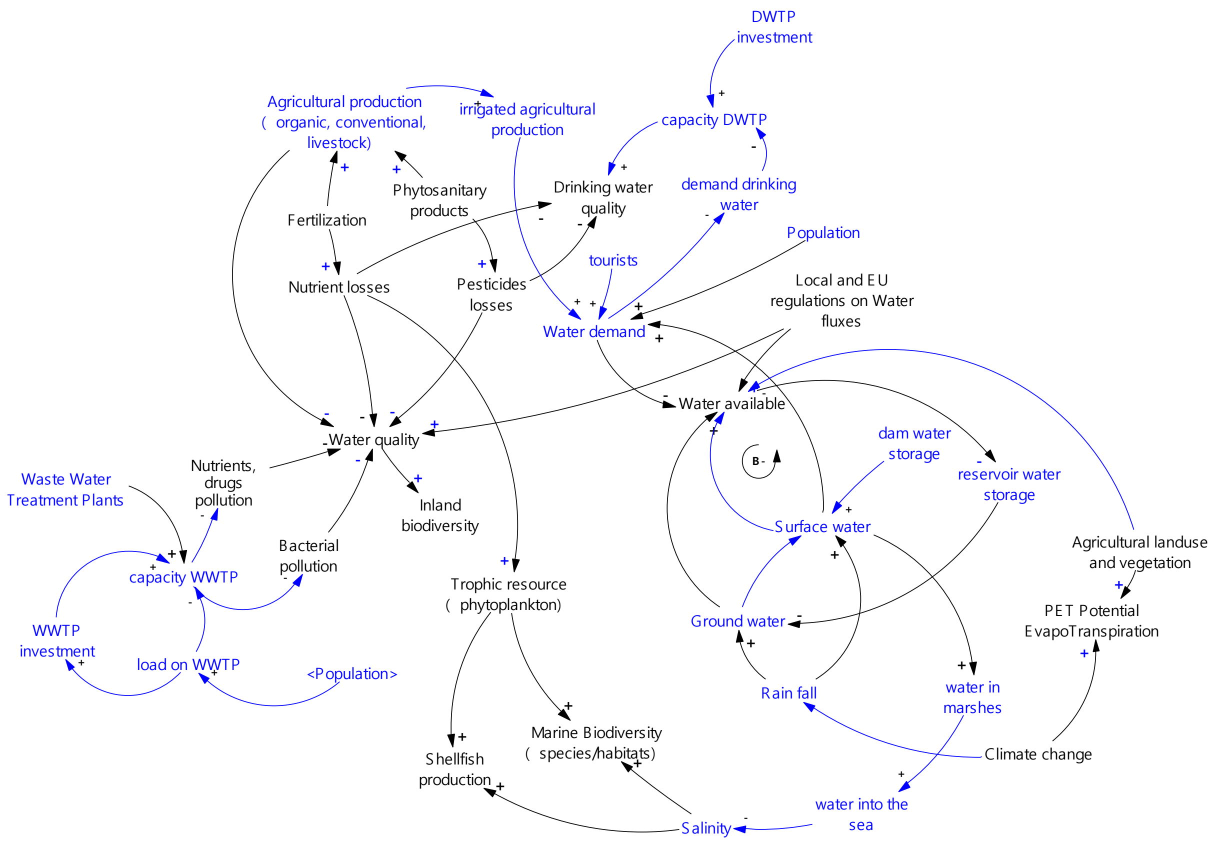


*Figure 60: CLD of the Water model with main variables in blue.*

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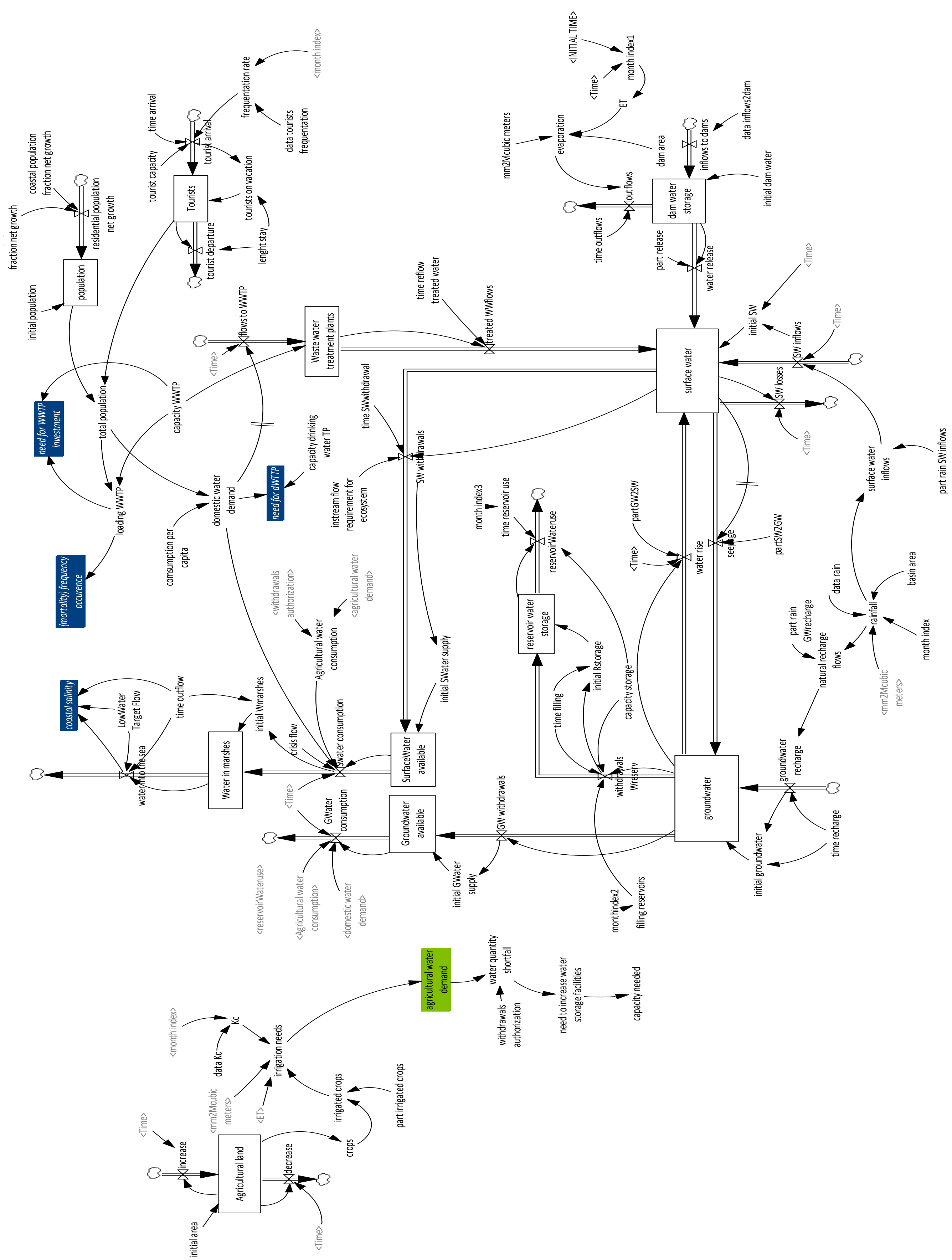


*Figure 61: Overview of the Stock Flow Water model with links to other sub models.*

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*Table 5: Main variables in the model. The INTEG () function used in the Definition is for the integration of flows with time.*

| Name | Unit | Role | Definition |
|---|---|---|---|
| **Dam water storage** | Mcubicmeters | Stock | Volume of water stored in the dam:<br>INTEG (inflows to dams-outflows-water release, initial dam water) |
| **SurfaceWater** | Mcubicmeters | Stock | Surface water body:<br>INTEG(SW inflows+treated WWflows+water release+water rise-ecosystem water inflow -seepage-SW losses-SW withdrawals, initial SW) |
| **Groundwater** | Mcubicmeters | Stock | Groundwater body:<br>INTEG(groundwater recharge+seepage-GW withdrawals-water rise-withdrawals Wreserv , initial groundwater) |
| **Reservoir water storage** | Mcubicmeters | Stock | Water stored in reservoir for irrigation:<br>INTEG (withdrawals Wreserv-reservoirWateruse, initial Rstorage) |
| **Water in marshes** | Mcubicmeters | Stock | Fresh water in the marshland area:<br>INTEG (water consumption-water into the sea,initial Wmarshes) |
| **Surface water available** | Mcubicmeters | Stock | Surface water available:<br>INTEG (SW withdrawals-Swater consumption, initial SWater supply) |
| **Groundwater available** | Mcubicmeters | Stock | Groundwater available:<br>INTEG(GW withdrawals-GWater consumption, initial GWater supply) |
| **WWTP** | Mcubicmeters | Stock | Water stored during the treatment in Waste Water Treatment Plant:<br>INTEG(0.9*domestic water demand-treated WWflows, capacity WWTP) |
| **GWater comsumption** | Mcubicmeters/ Month | Flows | Groundwater used:<br>(Groundwater available-(0.7*domestic water demand+0.6*Agricultural water consumption+reservoirWateruse))/Time |

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| Name | Unit | Role | Definition |
|---|---|---|---|
| **SWater comsumption** | Mcubicmeters/ Month | Flows | Surface water used:<br>IF THEN ELSE( SurfaceWater available-0.2*Agricultural water consumption-0.2*domestic water demand<=crisis flow , (SurfaceWater available-domestic water demand)/Time ,<br>(SurfaceWater available-0.2*Agricultural water consumption-0.2*domestic water demand)/Time) |
| **Agricultural water consumption** | Mcubicmeters/ Month | Auxiliary | Real water consumption from Agriculture: MIN (agricultural water demand+AgrWuse) , withdrawals authorization ) |
| **Ecosystem water inflow** | Mcubicmeters/ Month | Auxiliary | Minimum flows for ecosystem as set in EU regulations; IF THEN ELSE( surface water available/time inflows<=instream flow requirement/time inflows , instream flow requirement , surface water available/time inflows) |
| **Groundwater recharge** | Mcubicmeters/ Month | Auxiliary | Groundwater recharge:<br>natural recharge flows/time recharge |
| **GW withdrawals** | Mcubicmeters/ Month | Auxiliary | Withdrawal from groundwater:<br>groundwater available/Time |
| **Treated WW flows** | Mcubicmeters/ Month | Auxiliary | Treated waste water discharge to rivers:<br>Waste water treatment plants/time reflow treated water |
| **Water release** | Mcubicmeters/ Month | Flows | Water release from dams:<br>dam water storage*part release/time |
| | | | |
| **Population** | persons | Level | INTEG (residential population net growth, initial population) |
| **Tourist population** | persons | Level | INTEG(tourist arrival - tourist departure, tourists on vacation) |

Some variables in dark blue in the Stock Flow model are shared with the shellfish sub model: these are coastal salinity and the mortality rate with the shellfish farming sub model, in green with the Agriculture sub model (Agricultural water demand). Need dWTP (need for drinking Water Treatment Plant) and need WWTP (need for Waste Water Treatment Plant) will be included later in the infrastructure sub model.

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#### *3.4.3.2 The Shellfish Model*

##### *3.4.3.2.1 Model scope of the shellfish model*

The coastal zone and in particular shellfish farming needs fresh water. The first form of demand is related to Biodiversity that requires a restricted variation of the salinity in time and space. If we recognize the river-estuary-sea continuum, then removing fresh water amounts will affect the whole system based on this freshwater-salt water continuum. The mixture of fresh water and salt water, beyond the physical characteristics (presence of salt), has mineral and organic elements that enable the arrangement of a diversity of living organisms, and in particular plants (phytoplankton, micro-phyto benthos, macro-algae, etc.), the first link in the food chain of herbivorous such as oysters. A sustainable coastal system therefore requires the determination of the optimal shellfish biomass that can be produced without endangering biodiversity, which itself depends on use of coastal watersheds. To highlight these interactions, the shellfish farming model takes into account the 3 years production system and its dependence on the environment.

##### *3.4.3.2.2 Quantification of the shellfish model*

The Core of the shellfish SF model is focused on shellfish (oyster) production depending on phytoplankton concentration, the mortality rate due to poor quality water, with sales greatly dependent of the market demand outside the territory (export) and inside the territory depending on the tourist population. Direct and local sales imply limited transport costs with a relationship between sales and population densities on the coast. The proximity of high population densities increases the risk of viral pollution (with individual additional purification costs) and sometimes even bans on sales. *The increase of sanitary regulations entails additional costs for purification.* All these variables have been taken into account in the Stock Flow sub model for the shellfish farming production.

A shellfish stock ready to be marketed is the result of three years of breeding with inflows of juveniles (number of spat), individual growth that increases the stock in weight (both flesh and shell), mortalities that decrease the stock (in number), purchases and sales of shellfishes that increase or decrease the stocks. Relocation of production bringing oysters in or out of the stock for a given habitat (but not necessarily in or out a business) are not taken into account at this stage in the sub-model. The size-weight distribution of oysters ready to be marketed is important because demand and therefore prices are linked to the size of the animals.

Links with agriculture rely on Nitrogen concentration in water and the link with the water model are the salinity variable and the oyster mortality frequency.

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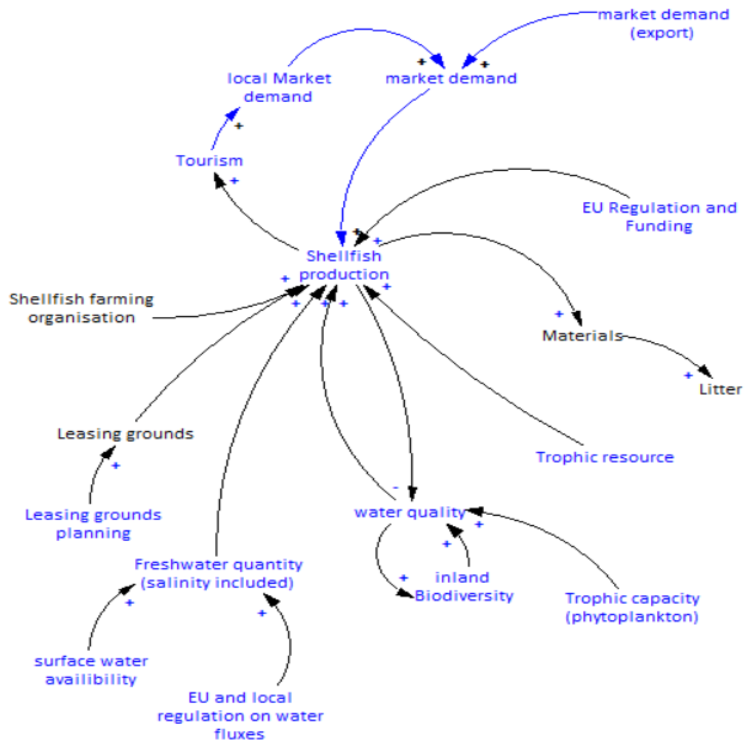


*Figure 62: CLD of the Shellfish model with main variables (in Blue).*

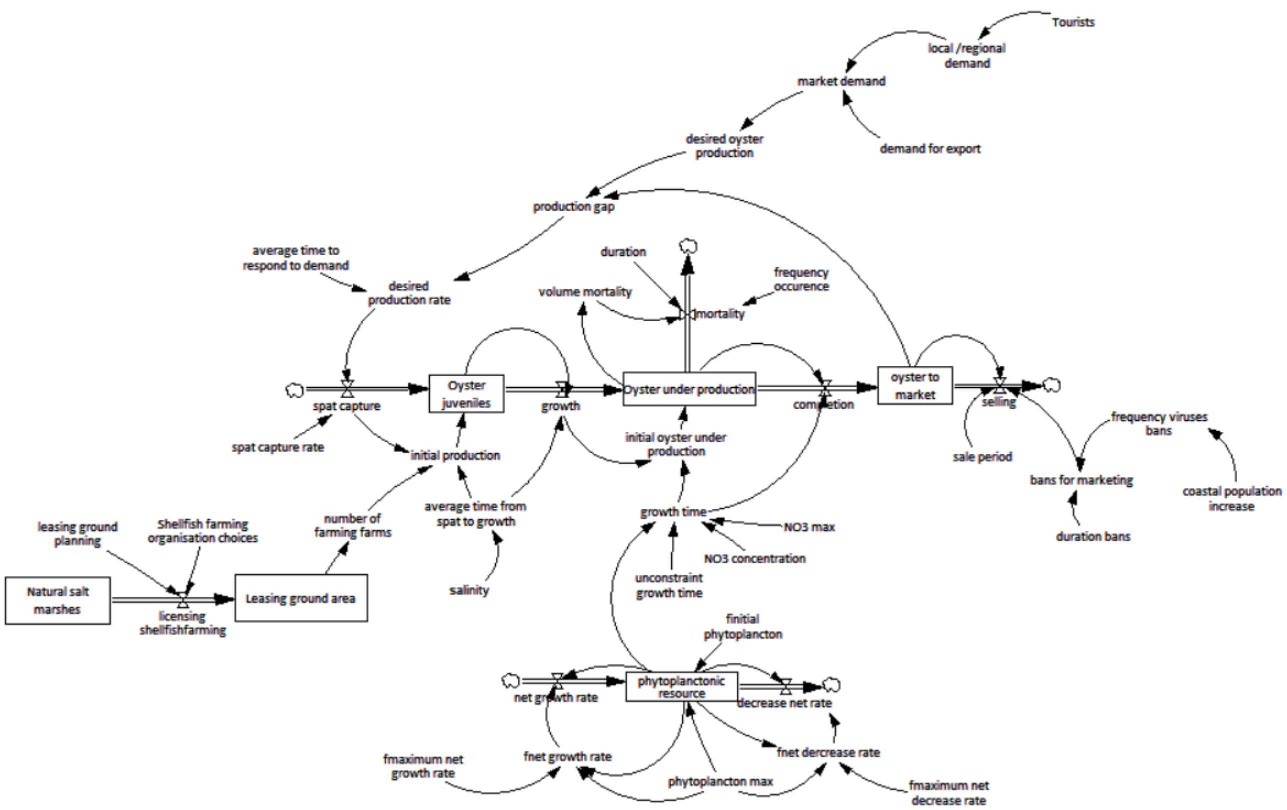


*Figure 63: Overview of the Shellfish farming StockFlow model.*

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The different steps of the oyster production from spat capture to sales are represented in the model to respond to demand. Production relies on demand but also on water quality for growth, mortality and marketing authorization.

*Table 6: Main variables in the Shellfish model.*

| Name | Unit | Role | Definition |
|---|---|---|---|
| **Oyster juveniles** | Ton | Stock | Stock of oyster juveniles(0-1 year)<br>INTEG (spat capture-growth, initial production) |
| **Oyster under production** | Ton | Stock | Stock of Oyster (1-3 years old):<br>INTEG (growth-completion-mortality, initial oyster under production) |
| **Initial production** | Ton | Auxiliary | Initial oyster stock for production: average time from spat to growth*spat capture |
| **Oyster to market** | Ton | Stock | Stock of oyster ready to be sold:<br>INTEG (completion-selling, 50000) |
| **Phytoplankton resource** | Ton | Stock | Stock of Phytoplankton:<br>INTEG (net growth rate-decrease net rate, finitial phytoplancton*phytoplancton max) |
| **Mortality** | Ton/year | Flow | Mortality of Oyster during the production process:<br>volume mortality/duration*PULSE TRAIN( 5 , duration , frequency occurrence , 50)<br>duration : 1 year; frequency occurrence: every 5 years dependant of water quality |
| **Desired production rate** | Ton/year | Auxillary | Production rate to respond to demand:<br>production gap/average time to respond to demand |
| **Selling** | Ton/year | Auxillary | Production permitted for selling:<br>IF THEN ELSE( bans for marketing>0 , 0 , oyster to market/sale period ) |

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### 3.4.3.3 The Agricultural Model

#### 3.4.3.3.1 Model scope of the agricultural model

The objective of the agricultural sub-model is to quantify the impact of the conversion of current agricultural systems to more sustainable (organic) systems on water quality and the impact of the evolution of irrigated crops on other activities and uses. These evolutions play a critical role in relation to the volumes water used by agriculture and the quantity of nitrate and pesticide fluxes discharged into rivers, at the outlet of the Charente catchment area, and downstream into coastal waters. The conversion towards a more sustainable agriculture will have also economic consequences in the MAL4 territory: on the infrastructure needed to ensure the storage of organic production, on the need for more land by agriculture (extensive systems) and on the development of new short supply chains.

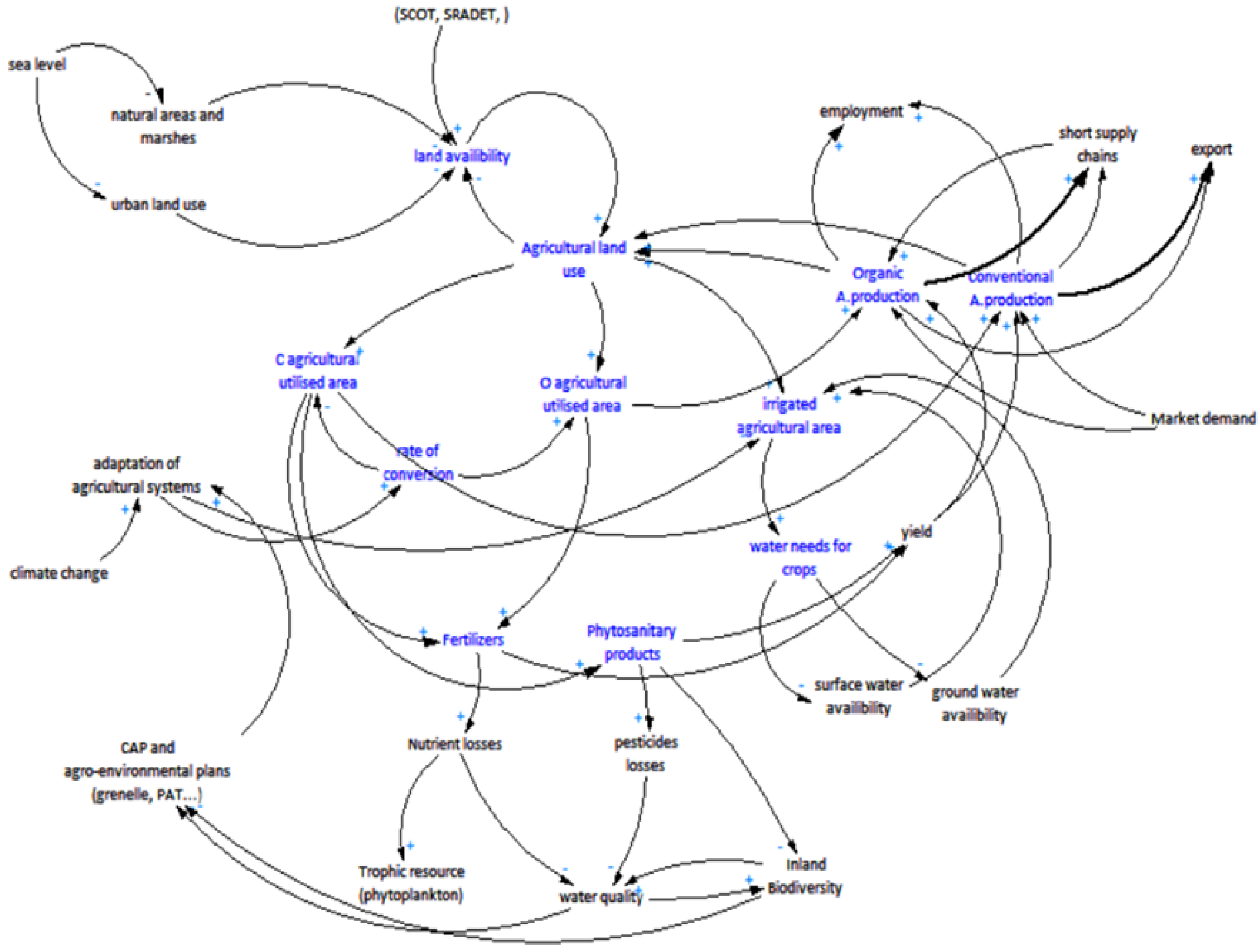


*Figure 64: CLD of the Agriculture sub model with main variables (in Blue).*

In the MAL4 simplified model, conventional and organic agricultural productions were merged into a single variable, as well as livestock. Irrigation of conventional and organic crops is quite similar, depending on the type of crop, but the fertilizers and pesticides are much less used by organic farming. Organic farming systems provide more employment, need more space per unit of production, and are more likely to generate local supply chains.  As far as livestock farming is concerned, its maintenance on the territory is linked to competition for space (land availability) and economic conditions. It can be taken into account globally in connection with the maintenance of grasslands in the catchment area and in coastal marshes (not included so far in the agricultural SD model)

Fertilizers are production factors for agriculture but they generate nitrogen losses to surface and groundwater, and by extension to coastal marshes and coastal waters. These nitrogen losses impact water quality and aquatic biodiversity (risk of eutrophication limited for this case-study due to high turbidity of coastal water). However not excessive Nitrate fluxes to coastal waters may play a favourable role for oyster growth. Results of a previous study on the Charente watershed will be used to link conventional and organic Utilised Agricultural Land with regard to the amount of nitrogen used for production (N indicator) and the potential N losses to water.

Depending on the type of crop grown, irrigation needs and therefore **water demand for irrigation** in spring and summer may vary. The type of system (conventional or organic) has little influence on this.

###### *3.4.3.3.2 Quantification of the agricultural model*

The agricultural SD model is focused on conventional and organic agricultural productions that depend on land and water available and on the market demand.

More water available leads to the development of agricultural production, notably irrigated, but this development will compete with other uses or economic activities requiring water. It is however not expected a reduction of agricultural water use from the conversion to organic systems that on the other hand requires more land because of reduced yields in comparison to conventional systems. The conversion of conventional farming systems to organic systems is considered as a way to reduce impact of farming on water quality. This conversion rate will however depend on the profitability of organic systems. The actual profitability of organic farming system is due to high farm gate prices even if yield are much lower than for convention farming but an increase of organic production may lead to a decrease of selling prices with a balancing loop for its development. In addition, such a change of farming systems will require the development of specific infrastructure (storage). New modes of consumption (short supply chains) can be expected to develop as a result of the progressive development of organic farming. On the coastal zone, sea-level rise and flooding due to climate change could lead to lower agricultural land availability (cf. the Dike infrastructure sub-model).

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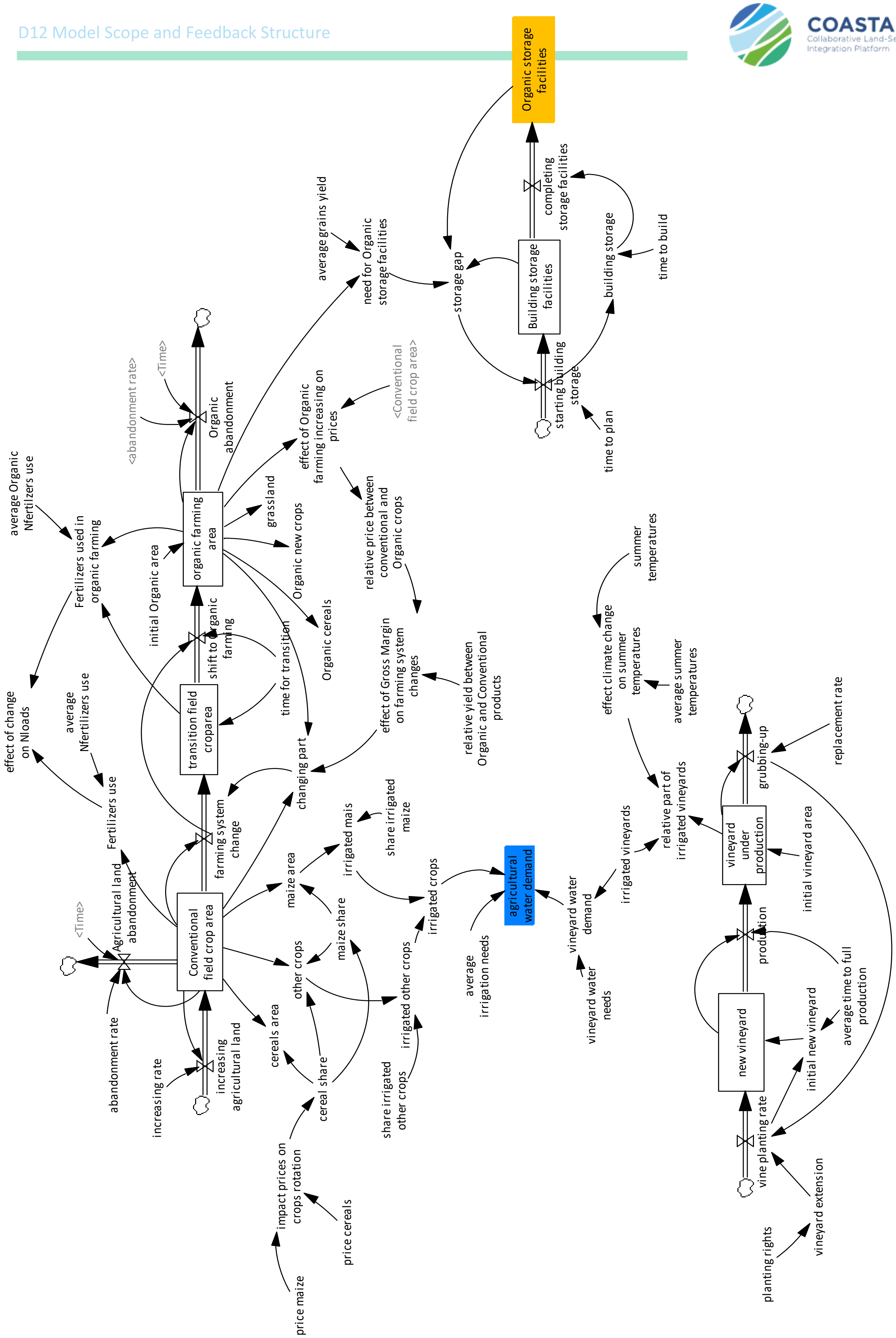


*Figure 66 : Overview of the Agriculture SF sub- model..*

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*Table 7: Main variables in the Agricultural sub model.*

| Name | Unit | Role | Definition |
|---|---|---|---|
| **Conventional field crop area** | Hectare | Stock | Field crop area with conventional system: INTEG ( (increasing agricultural land-Agricultural land abandonment-farming system change),620000) |
| **transition field crop area** | Hectare | Stock | Areas in conversion to organic farming: INTEG ( farming system change-shift to Organic farming,farming system change*time for transition) |
| **Building Organic storage facilities** | Tons | Stock | Construction of storage facilities for Organic production: INTEG (starting building storage-completing storage facilities,0) |
| **Organic storage facilities=** | Tons | Stock | storage facilities built for Organic production INTEG ( completing storage facilities, 5000) |
| **Organic farming area** | Hectare | Stock | = INTEG (shift to Organic farming-Organic abandonment, initial Organic area) |
| **vineyard under production** | Hectare | Stock | Productive vineyards: INTEG (production-"grubbing-up",initial vineyard area) |
| **irrigated crops=** | Hectare | Auxiliary | All crops irrigated: irrigated maize + irrigated other crops |
| **effect of Gross Margin on farming system changes =** | Dmnl | Auxiliary | Economic effect in changing to organic: WITH LOOKUP (relative yield between Organic and Conventional products/relative price between conventional and Organic crops) |
| **changing part** | Dmnl | Auxilliary | Part of the conventional field crop in conversion: organic farming area/Conventional field crop area)*effect of Gross Margin on farming system changes |

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#### 3.4.3.4 The Infrastructure Model

##### 3.4.3.4.1 Model scope of the infrastructure model

The residential population in the coastal zone has increased continuously over the last 30 years and it is unlikely that this trend will change in the short and medium term.  There will be consequently a need for the construction of new housing to cater for the increase in residential population. Attractiveness of the coastal zone with its beaches and historical towns draws many tourists to the region increasing the needs for new tourist accommodation.

Port-Atlantique (La Rochelle) is committed to a process of Ambition Carbone free with La Rochelle urban agglomeration. The modal shift in the hinterland from road to rail transport (14 to 25% by 2020) is in line with the application for the EU-TENT policy to enhance rail transport at a European scale and increase public investment in railways.

- To support changes in traffic due to changes in the economic models, the improvement of its competitiveness with a more performant logistic, the development of the port capacity (area) and the new services are part of the strategic development project of the port. This development implies investments in storage facilities for operators, extension of existing piers to enlarge capacities but also to support renewable wind energies (waves and wind power) from a multimodal platform (maintenance and construction). The port engagement in the territorial strategy implies tight relationships with hinterland industrial actors (cereals, agribulk for farm inputs) to broaden material flows.
- Increase in average sea level will require to better dimension structures in the coastal zone (rising of port platforms) but also the enhancement of dikes in populated flat coastal areas. With its 450 km of coastline, the coastal zone of the MAL4 is indeed particularly vulnerable to strong storms and the objective set after the violent storm Xynthia in 2010 that killed 47 people, is to protect the coast from a similar or even greater weather event (+ 20cm flood level) . The coastal protection reinforcement plan, also called "Plan Digues", is the largest project of this kind in France to strengthen coastal protection. After having already built the most urgent works, it is deploying all along the coast as well as in estuary areas. In the next decades, due to climate change, it is expected that storms will be more frequent along with a sea level rise. A part of the Agricultural land in marshes could probably be abandoned because of this rise resulting in increased salinization of the soils.

We base the SF model on the following dynamic Hypotheses:

- Residential coastal house building will be developed until space competition and traffic congestion particularly in summer will stop its expansion
- Port will develop to increase its throughput and cereals export capacity but will diversify to other sectors (renewable energy, containerships traffic) in case of decline of agriculture in the hinterland. Railways extension will expand material flow and port utilisation that will imply increase of port utilisation and an increase in port throughput thanks to technology and numeric innovation.

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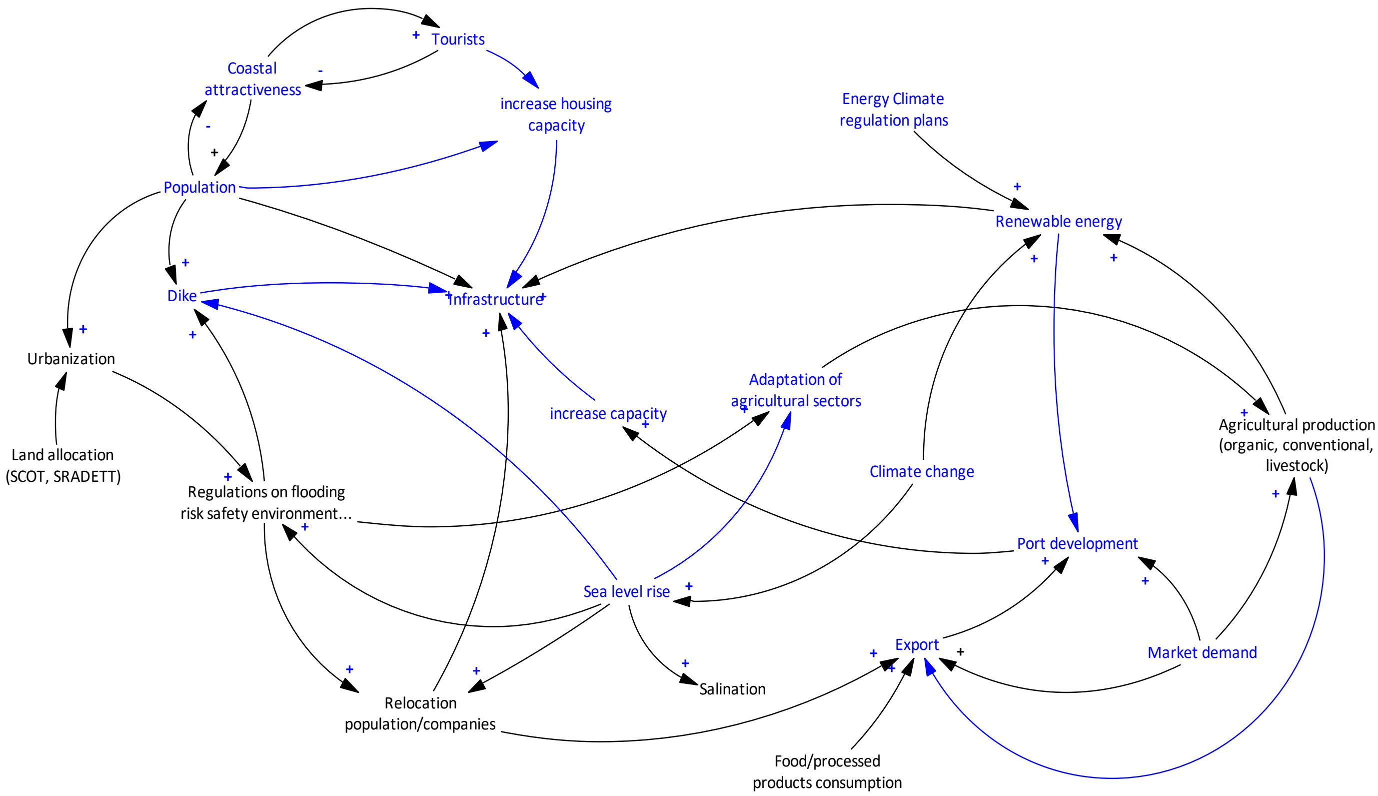


*Figure 67: CLD of the Infrastructure model with main variables (in Blue).*

#### 3.4.3.4.2 Quantification of the infrastructure model

The overview of the infrastructure sub-model is indicated in the following diagram where port capacity, railways development, roads network, housing and dikes to prevent flooding are presented as stocks. As development of infrastructure takes time, we have explicitly added for each of these stocks 'under construction' precursors as this will facilitate reproducing the dynamics of the development process. Links to the agricultural sub-model are highlighted in green. Only main variables for the Dikes part of the sub-model are indicated in the table presented herewith for information. Infrastructure development for waste water treatment plants and drinking water treatment plants will be included further with variables shared with the water sub-model.

*Table 8: Main variables in the Dikes part of the Infrastructure model.*

| Name | Unit | Role | Definition |
|---|---|---|---|
| **Dikes** | Km | Level | Dikes:<br>INTEG(completing dikes, 20) |
| **Dikes under construction** | Km | Level | Dikes under construction:<br>INTEG ( starting dike construction-completing dikes, 0) |
| **Building dike** | Km/year | Auxilliary | Construction process<br>DELAY3(starting dike construction, time to build dikes ) |
| **construction effect on** | Dml | Auxilliary | Effect on flooding risks reduction: |

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| | | | |
|---|---|---|---|
| **risk reduction** | | | With LOOKUP (dikes under construction/Dikes) |
| **risk of floodings** | 1/year | Auxilliary | construction effect on risk reduction*acceptable risk*effect of sea level rise on flooding frequency |
| **indicating dikes** | km | Auxiliary | pressure to expand dikes*fraction land at risk*Agricultural coastal land/acceptable risk |
| **pressure to expand dikes** | Dmnl | Auxiliary | With LOOKUP (risk of flooding/acceptable risk) |
| **coastal land abandonment** | Hectare | Auxiliary | fraction land at risk*Agricultural coastal land*effect of flooding of coastal farmland abandonment |
| **Average dike demand** | Km | Auxiliary | SMOOTH( indicating dikes , time to demand) |
| **starting dike construction** | Km/year | Flow | dike gap/time to plan dikes |
| **Dikes** | Km | Level | Dikes:<br>INTEG(completing dikes, 20) |
| **Dikes under construction** | Km | Level | Dikes under construction:<br>INTEG ( starting dike construction-completing dikes, 0) |
| **Building dike** | | Auxiliary | Construction process<br>DELAY3(starting dike construction, time to build dikes ) |
| **construction effect on risk reduction** | Dmnl | Auxiliary | Effect on flooding risks reduction:<br>With LOOKUP (dikes under construction/Dikes) |
| **risk of floodings** | 1/year | Auxiliary | construction effect on risk reduction*acceptable risk*effect of sea level rise on flooding frequency |
| **indicating dikes** | km | Auxiliary | pressure to expand dikes*fraction land at risk*Agricultural coastal land/acceptable risk |
| **pressure to expand dikes** | Dmnl | Auxiliary | With LOOKUP (risk of flooding/acceptable risk) |
| **coastal land abandonment** | Hectare | Auxiliary | fraction land at risk*Agricultural coastal land*effect of flooding of coastal farmland abandonment |
| **Average dike demand** | Km | Auxiliary | SMOOTH( indicating dikes , time to demand) |

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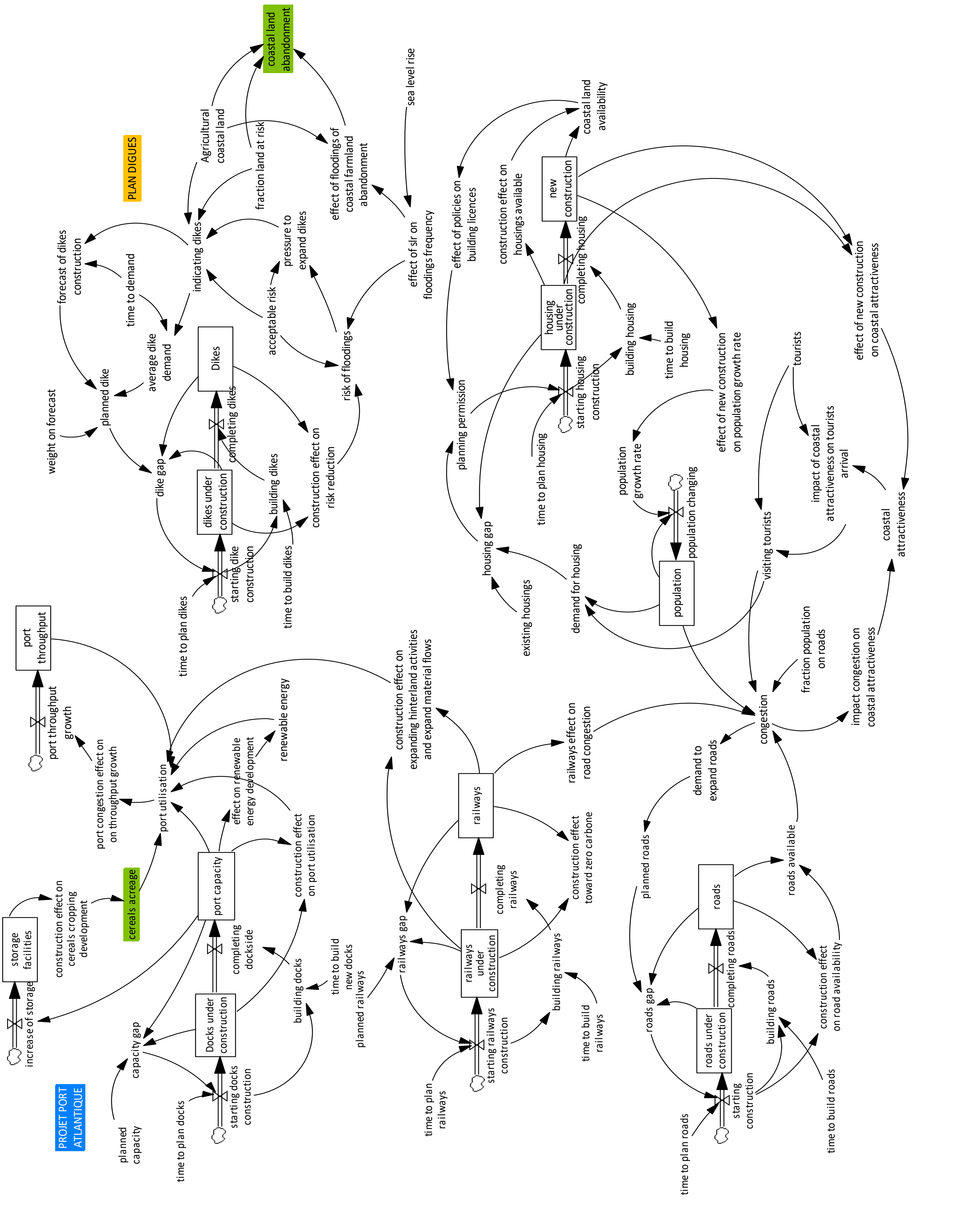


*Figure 68: Overview of the StockFlow Infrastructure model.*

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### 3.4.4 Problems that can be addressed with the SD models

The common objectives of the MAL4 territories for a desirable future (2040-2050) were set by stakeholders during the workshops: these are the restoring and preserving of natural environments and the limiting impact from economic activities and the population on the water resources, soils and biodiversity. The preservation and/or development of main economic activities in the area such as agriculture, shellfish farming, tourism and port activities are also set in the objectives. There is then a need to explore different scenarios on how to reach these objectives that are sometimes conflicting. However by highlighting interdependencies between activities and possible synergies, by identifying the most relevant pathways and actions to reach this desirable future, SD models can help analyse the potential consequences of actions and might help find pathways to sustainability.

For MAL4, the key problems that can be addressed with the SD models are the following:

-Evolution of agriculture: the agriculture sub-model can help assess the consequences of agriculture development on land and water availability, on infrastructure development, on additional storage needed to develop more sustainable systems or how economic conditions matter in the shift from conventional to organic farming systems. It will above all help evaluate the consequences of the development of sustainable farming systems and crops on the agricultural water demand, water availability and water quality. On the other hand, the development of organic farming and short supply chains may provide other opportunities for new crops and new supply chains. Development of organic agricultural products less related to the export may have nevertheless consequences on port activities. Assessment of the controversial issue of water storage and the consequences of reservoir water capacity increase on water supply and activities requiring water other than agriculture will be possible with the SD models.

-Impact of the increase of population (residential and tourism): the increase of population on the coastal zone will very likely continue although the desirable future implies the maintenance of urbans areas and associated services within all the territory. This population increase will have consequences on the building of housing, the quality of fresh water inflows into the sea, the need for new investments to increase the capacity of waste water treatment plants, the traffic congestion or additional costs for shellfish farms caused by purification needs.

-Development of sustainable shellfish farming: the sub model shellfish farming can help identify the conditions of the maintenance and development of sustainable shellfish farming in the area. The use of current locations close to the coast implies that the water quality of coastal waters (salinity, low concentrations in pesticides and bacteria, level of nutrients) provides the best conditions for oysters' growth and quality for selling. The shellfish sub model explores more details regarding the impact of water quality on shellfish production (frequency of mortality, spat capture rate) as well as the impact of market demand and coastal tourism development on local sales

-Sustainable port development: the sub models Infrastructure will explore the strong interactions between agriculture, intensive or sustainable, and ports activity. Port development could have an impact on agricultural intensification in the hinterland with consequences for the water resources.
-Development of infrastructure: Impact of the building of dike to prevent sea-level rise or more frequent flooding with its consequence on coastal land abandonment and building housing on coastal areas could be addressed by the SD model.

### 3.4.5 Data sources

The INRAE data management plan identifies all sources of data that will be used by the SD models. This inventory involves analysis and evaluation of the availability, quality and usefulness, spatial-temporal scales and periodicity of the data. Metadata files are filled by researchers and controlled by a data manager. The structure of the file stored (.csv) preserves future interoperability within the Coastal project. Strict internal rules are laid down to comply with the GDPR Directive (personal data from surveys, workshops records...). Only two people (IT specialists) have a write access to data and a small number of partners (people who need to analyze and use the data) have read-only access.

Some relevant sources of data which were identified during this step of the modelling process:

Synthèse hydrogéologique par bassins versants de la région Poitou-Charentes – Relations nappes-rivières. F. Bichot et al, BRGM/RP ; 53767 FR, 2005.

Les eaux souterraines en Poitou-Charentes ; F. Bichot et A. Gennat ; BRGM Poitou-Charentes, Février 2013

Pruyt, E., 2013. Small System Dynamics Models for Big Issues: Triple Jump towards Real-World Complexity. Delft: TU Delft Library. 324p http://simulation.tbm.tudelft.nl

Observatoire regional de l'Agriculture biologique, Données 2017 ; Les chiffres de l'Agriculture en Nouvelle Aquitaine ; Agence bio 2018/OC, Agreste (mémento régional 2017)

Plan d'Aménagement et de Gestion Durable (PAGD)

Schéma d'Aménagement et de Gestion des Eaux SAGE du bassin versant de la Charente ; Plan d'Aménagement et de -Gestion Durable de la ressource en eau – Version Commissions Thématiques ; Décembre 2017

B. Dangerfield (ed.), System Dynamics, System Dynamics and its Contribution to Economics and Economic Modeling

https://doi.org/10.1007/978-1-4939-8790-0_539

System Archetypes I: Diagnosis Systemic Issues and Designing High-Leverage Interventions; Daniel H. Kim, Pegasus Communications, Inc.

SAGE Charente, Etat initial; Eaucea, Acteon 02/2012

Agreste n° 316 - juillet 2014 - Recensement de la conchyliculture 2012 : 160 000 tonnes de coquillages commercialisés

Agreste Charente-Maritime - Recensement conchylicole 2001 : Charente-Maritime, ses conchyliculteurs, ses huîtres, ses coquillages

Agreste n° 16 - Octobre 2014 - Recensement de la conchyliculture 2012 : La Charente-Maritime est le premier département producteur de coquillages . http://www.agreste.agriculture.gouv.fr

SAFER Poitou Charentes, PPAS 2015-2021 ; Orientations Politiques et stratégiques; Programme pluriannuel d'activité de la SAFER Poitou Charentes pour la période 2015-2021; 11/2014

Observatoire Régional du Tourisme ; Les Chiffres Clés du Tourisme ; www.ort-poitou-charentes.com

Flash Info Maline 2008-2018, dix ans déjà …de communication sur les mortalités d'huîtres et de moules dans les Pertuis Charentais ; Ifremer ; 08/2018

Façade Sud-Atlantique, Monographie maritime 2017 Direction interrégionale de la Mer Sud-Atlantique

Agreste, Analyses & Résultats, Nouvelle-Aquitaine, Mai 2019 - numéro 67

Charente Tourisme, Chiffres Clés 2018 Charente et Charente-Maritime

Mémento de la statistique agricole Agreste Nouvelle-Aquitaine Novembre 2016

Port Atlantique La Rochelle ; Projet stratégique 2020-2024

Organic farming ambition 2022, French Ministry of Agriculture

Oracle Nouvelle Aquitaine (climate change if Aquitaine region) 2018 edition

Food supply chains in Nouvelle Aquitaine (2018) French statistics

Quantitative management of the water resources, EPTB Charente –annual edition

Bastan et al, 2017 - Sustainable development of agriculture: a system dynamics model – Kybernetes, 47, doi10.1108.

Gergely Honti, Gyula Dörgő, János Abonyi, Review and structural analysis of system dynamics models in sustainability science, Journal of Cleaner Production, Volume 240, 2019, 118015, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2019.118015.

Rogelio Oliva, Model calibration as a testing strategy for system dynamics models, European Journal of Operational Research, Volume 151, Issue 3,2003, Pages 552-568, ISSN 0377-2217, https://doi.org/10.1016/S0377-2217(02)00622-7.

Turner et al, 2016 - System Dynamics Modeling for Agricultural and Natural Resource Management Issues: Review of Some Past Cases and Forecasting Future Roles - Resources 2016, 5, 40; doi:10.3390.

### 3.4.6 Planning

In the next steps it is planned to finalize the stock flow models, by adjusting equations used so far and then to move to the next step of calibration with the available historical values. Once models have been shown to be adequate and consistent with historical behaviour, it will be possible to move to the actual testing of estimated parameters. This step will be time consuming and might be not completed given the number of parameters used in the different models before the scenarios analysis that is being planned relatively quickly before returning to stakeholders.

The model building process in COASTAL is also an iterative process and is to be expected when the model results will be presented to the MAL Actors and stakeholders that their feedback will result in additional changes to the models. Additional variables could be included after the second round of workshops if these are considered as essential and have not yet been considered in the present sub model.

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

### 3.5.1 Problem scope of the land sea system

The Danube River Basin is Europe's second largest river basin, with a total area of 801,463 km$^2$(World Bank, 2014a). It is the world's most international river basin, flowing through the territory of 19 countries. The ecosystems of the Danube River Basin are subject to increasing pressure and serious threats of pollution from agriculture, industry, and urbanization[5]. The lowlands, plateaus and mountains of Romania and Bulgaria form the Lower Basin of the River Danube. Beyond the Iron Gates, the Lower Danube flows across a wide plain; the river becomes shallower and broader, with several major islands, and the current slows down considerably. The river finally divides into three main branches (the northern Chilia, the central Sulina and the southern Sfântu Gheorghe) near Tulcea in Romania, some 80 km from the Black Sea, forming a delta with a total area of 4,525 km$^2$ of which 3,510 km$^2$ on Romanian territory. As both the largest remaining natural wetland and second largest river delta in Europe, the Danube Delta is one of Europe's most valuable habitats for wetland wildlife with 16 strictly protected areas. Pollution and discharge manipulation from upstream have a huge effect on this highly biodiverse area. The universal value of the reserve was recognised in 1990 by the Man and Biosphere Programme of UNESCO through its inclusion in the international network of biosphere reserves, a wetland of international importance especially as waterfowl habitat under the Ramsar Convention and inclusion of the strictly protected areas in the World Heritage List under the World Heritage Convention[6].

The Danube Delta Biosphere Reserve (DDBR) includes three sections: the "core Delta", the area between the Chilia and Sf. Gheorghe branches of the Danube River; the lakes to the South; and third, an area along the Danube River west of Tulcea City. The DDBR comprises also 1,030 km$^2$ of marine waters (Black Sea) up to the 20m bathymetric contour (isobath).

In addition to supporting a high level of *biodiversity*, the Danube Delta Region provides many benefits for humans (ecosystem services). It has an important effect on *water quality*, and *nutrient* retention, especially for the Black Sea ecosystems. Moreover, it provides extensive economic and environmental benefits to the entire region: the socio-economic benefits of the wetlands to local communities living in and around the Danube Delta are very important. Practically, all aspects of the lives of the delta's inhabitants are related to water in one way or another. The Danube River and its branches, and several canals are the major sources of water for industrial, agriculture (irrigation) and domestic use for local communities. They are also used for navigation by both commercial and public ships and vessels, boats, and canoes. The main natural resources represented by fish, reed, pasture, natural and planted forests support traditional economic activities undertaken by local communities. Fishery is by far the most exploited resource, with about 7000 t per year supporting commercial, subsistence and recreational

[5] https://www.icpdr.org/main/danube-basin

[6] http://www.ddbra.ro/en/danube-delta-biosphere-reserve/danube-delta

fishing, mostly consisting of freshwater species. The reed beds have the potential to produce about 40,000–50,000 t of reed per year, and the pastures support grazing sheep, cattle, pigs, and horses. The use of reed has a long history in the Danube Delta, with local people building shelters for fishermen, refuges for cattle and sheep, roofs for houses, fences for yards, etc. When used for thatched roofs elsewhere in Europe, it would imply that significant income is obtained.

Agriculture is practiced, both in polders for cereal crops (wheat, barley, maize), sunflowers, and, on a smaller scale, for family needs (vegetables, fruit trees, vineyards) (Baboianu, 2016).

Thus, the most significant physical and ecological feature of the DDBR is its vast expanse of wetlands, including freshwater marsh, lakes and ponds, streams, channels, and seawater. Only 9% of the area is permanently above water. Life for the 10,000 residents of the core Delta is challenging and access to essential social and economic services is limited. Water transport is often the only option to reach and travel between destinations in the core Delta. The area also has lower access to basic services, such as tap water and sewerage, than the neighbouring rural areas. Health and education services are also constrained by inaccessibility and a decreasing population (World Bank, 2014b).

Land-sea interactions are at the core of our study case. Hence, we will include in the model only the core delta, the southern area (as an adjacent agricultural area), and the marine waters (Black Sea) part of DDRB. However, all other areas contributions are considered through several exogenous variables (Figure 69).

A general conclusion of the stakeholders meetings outlined that governance and excessive bureaucracy are disturbing the economic activity (planning, facilities for investors (lack of), lack of compensatory measures, tourism, infrastructure) and social areas (health, incomes, protection, jobs), avoid 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. Agriculture has clear impacts on both inland and coastal water quality and the locals are not aware of causes, effects and impacts of the pollution on the Black Sea and even on the surrounding neighborhood. The agriculture is for subsistence 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 an artificial population "growth" which is not sustained by the "real" economic development.

After the delta's designation as a biosphere reserve, activities are only allowed in economic zones and buffer zones, under strict supervision of Danube Delta Biosphere Reserve Authority (DDBRA). No activity is allowed in the strictly protected areas or core zones. The most important conflict is between the rights of the local population to use resources that the residents of deltaic villages were traditionally ascribed before that area was declared a biosphere reserve (Vaidianu et. al, 2014).

Consequently, a dual challenge for the sustainable development of the Danube Delta is the conservation of its ecological assets and the improvement of the quality of life for its residents and to strike a balance between protecting the unique natural and cultural assets of the DDBR, and meeting the aspirations of the region's inhabitants to improve their living conditions and seek better economic opportunities (World Bank, 2014a). The management of the Danube Delta should take into consideration several needs for the short and medium terms. For example, in the short term, the implementation of a wetland restoration program to increase the natural flooded area in abandoned polders for agriculture and fish farming should be continued. In addition, measures are needed to reduce the impacts of the more ecologically damaging economic activities (including navigation and related hydrotechnical works, over-exploitation of natural resources (especially fish)) and other land uses according to the carrying capacity of the ecosystems and pollution control. The living standards of local communities should be improved through the extension of drinking water supply, wastewater treatment networks, waste management, green energy use, and the involvement of the local communities in the direct management of the wetlands and their resources is another urgent need (Baboianu, 2016). On the other hand, the conflict between conservation (biodiversity) and economic development becomes precarious in developing countries. Many authors consider that environmental issues associated with the lack of environmental awareness are a consequence of poverty or at least connected to it, particularly in developing countries, or when natural resources are not seen as solutions for reducing poverty through their sustainable use (Petrisor et al., 2016). Among the causes of conflicts, economic activities are the dominant ones; in particular, agriculture seems to be a source of conflicts. Generally, conflicts appear due to restricting access to resources, reducing the rights derived from ownership, ignoring the particularities of local cultures. Moreover, low accessibility, lack of funding, lack of planning and design and the pressure of tourism are possible sources of conflict. Tourism generates conflicts due to the behavior of tourists, particularly through cultural differences and their lack of interaction with the locals, which ultimately determine an erosion of the local traditions, but also due to an uneven return of benefits. Tourism attracts jobseekers and even immigration to protected areas. The number of tourists visiting protected areas is conditioned by infrastructure. While the remoteness of these places usually prevents massive tourism, the development of infrastructure resulting from the protection status can generate potential threats (9). In the Danube Delta, due to its high biodiversity and uniqueness of landscapes, the delta attracts about 150000 tourists every year, which is ten times the number of inhabitants[7].

In accordance with its Biosphere Reserve stature, the Danube Delta is expected to be governed by policies converging towards an integrated economic, societal, cultural, and environmental sustainability (Petrişor et al., 2016). The conservation management policies for the unique pattern of closely tied habitats and ecosystems in the Danube Delta have often led to tensions between the management authorities and the local populations. Disagreement persists in matters such as the regulation of fishing, hunting and other economic activities, taxation and transport policies or the establishment of restricted areas within the Delta (Bell et al., 2009). While past anthropic activities in the Danube Delta led to important impacts on the natural environment there are also economic activities which can be optimized in order to become sustainable on the long term, such as ecotourism, reed harvesting and processing, small-scale businesses based on traditional activities (Sbarcea et al., 2019)..

[7] http://ecopotential-project.eu/images/ecopotential/documents/D7.3.pdf

The unique ecosystem of the North-Western Shelf of the Black Sea is burdened by excessive loads of nutrients and hazardous substances from the coastal countries and the rivers that discharge into it and the Danube is the river with the highest discharge. Pollution inputs and other factors radically changed Black Sea ecosystems beginning around 1960. During the decades that followed, the Black Sea ecosystem went into a state of collapse. Beaches in Ukraine and Romania were piled with dead and decaying sea plants and animals. Losses were estimated to be as high as 60 million tons. Other pressures on the Black Sea ecosystems include organic pesticides, heavy metals, incidental and operational spills from oil vessels and ports, overfishing and invasions of exotic species.

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 prevented achieving the Good Environmental Status by 2020, as required by the EU-Marine Strategy Framework Directive. The increased rates of eutrophication, pollution are important stressors for the Black Sea ecosystem (INCDM, 2018).

The conclusion of all COASTAL meetings (with stakeholders, mental mapping seminar and MultiActorLab) conclusions were in line with the 2030 vision for Danube Delta "An attractive area – with precious biodiversity and vibrant, small/medium scale (artisanal and modern) agriculture and business - where people live in harmony with nature; integrating economies of tourism, farming and fishery; and supported by urban service centres". The vision represents a challenge of reconciling economy, society and the environment which becomes prominent in biosphere reserves, and the human settlements situated within Danube Delta must be managed such that they achieve equally social, economic and environmental sustainability and make up a successful case study (MDRAP, 2016).

Therefore, designing coherent actions requires acknowledging the corresponding system's feedback structure. A feedback is a chain of causal relationships that leads back to its origin (Collste et al., 2017). For example, if in the region investments in waste management are planned this may over time, result in cleaner waters and villages which may in turn increase the region's attractiveness for tourists. With an effective tax system and local empowerment, increased attractiveness could lead to higher local revenues which enable new investments that could be used to further improve the waste management in the area. This example involves significant delays, which may need to be considered for successfully assessing the long-term effects of policy choices. From a systems perspective, a multitude of such feedback loops act concurrently to shape a region's development (Collste et al., 2017).

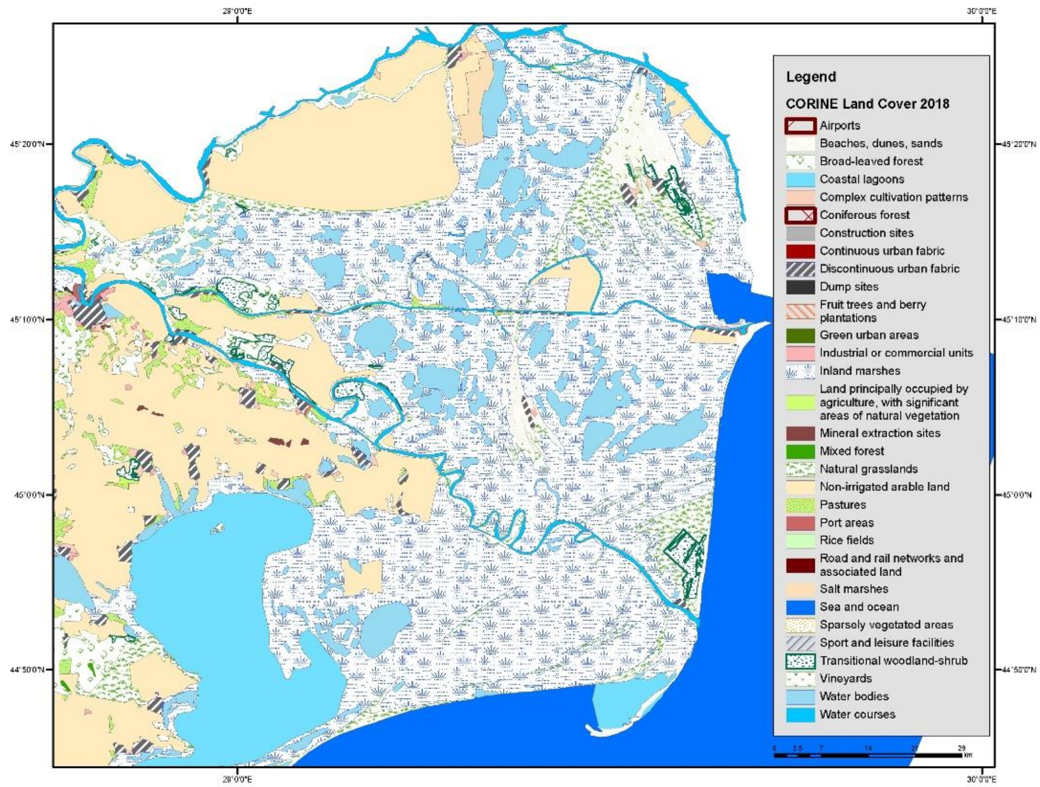


Figure 69: Map of the geographic area - Danube's Mouths – Black Sea case.

The goal of the model is to explore alternative scenarios to improve the quality of life and sustainability within Danube Delta Biosphere reserve and its marine waters (Black Sea) as one of the most impacted area along the Romanian littoral. Land-sea interactions in the coastal MAL5 region were identified through separate sector workshops and a combined multi-sectoral workshop as part of WP1 in COASTAL project. The land sea interactions we will consider in the model (Figure 70) are defined by the ecosystem-based management approach:

- Improve Sustainability of the area. Setting up coherent regulatory framework (**Legislation**) on development strategies for land (agriculture, rural development, freshwater fisheries, tourism) and marine (fishery and aquaculture) activities will lead to proper implementation of ecosystem based management principles.
- Adaptation and Mitigation to **Climate change**. As the Danube's discharge receiver, the Black Sea is impacted by increased discharge of freshwater and pollutants (from **agriculture** and inadequate infrastructure of **rural development**) and seawater temperature increase (**marine fishery**).
- Use of Knowledge to improve sustainability and climate change impacts in the area- **Education, training and research** at different levels – workforce, economic activities development, environmental monitoring, scientific research.

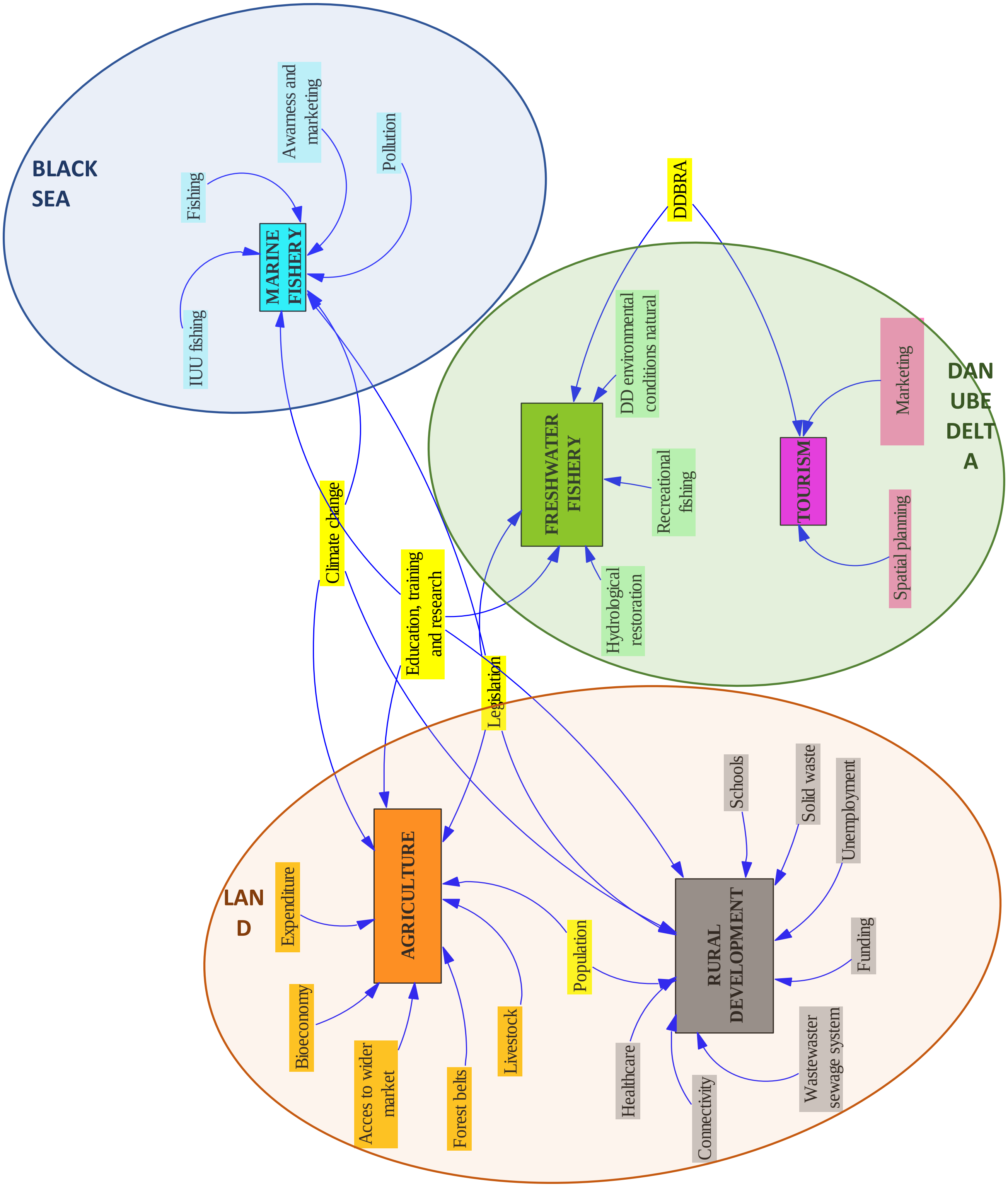


*Figure 70: Land-Sea interactions - MAL5 – Romania, Danube's Mouths – Black Sea case. DDBRA= Danube Delta Biosphere Reserve Authority; DD= Danube Delta; IUU = illegal fishing*

### 3.5.2 Overview of land-sea interactions

To analyse the stakeholders meeting outputs in the SD model we classified the land-sea interactions "layers" into:

- Economy - Agriculture, Fishery (Freshwater and Marine) and Tourism
- Social – Rural development - basic services and connectivity in Danube Delta

Even though the environmental aspects and ecosystem management were not an important issue during the stakeholders meeting we envisaged their clear interlinkages mainly because of the Danube as the end carrier of all substances discharged into the Black Sea and as the physical environment on which these layers rely (Figure 71).

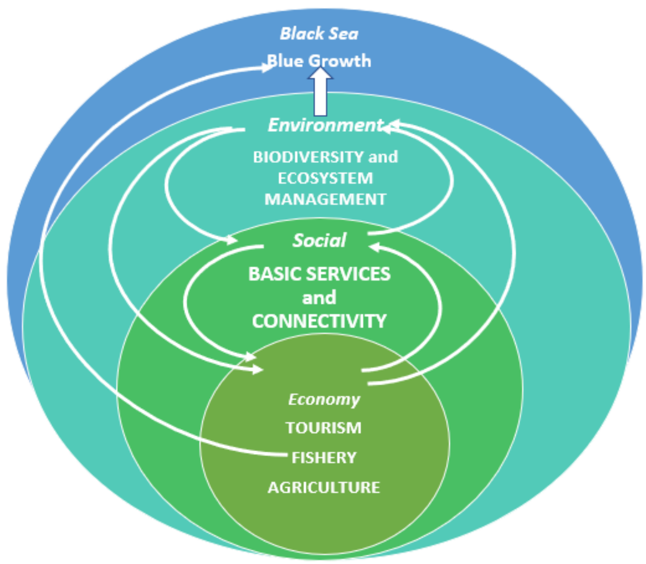


*Figure 71: Land-Sea interactions and sub models in the Danube's Mouths – Black Sea case.*

As the overall CLD produced during WP1 was considered unclear, it was decided to start from the sectoral CLD's when producing the SD model(s). Based on the CLDs derived during the sectoral workshops and layers presented above we identified several sub-models from the overall CLD that will be further developed in the following chapters on quantification. More specifically sub-models will be presented for:

- Agriculture
- Fishery (freshwater and marine)
- Tourism
- Rural development
- Ecosystem management (Environment), as an intermediate between the sub-models above

The transition of CLDs to SD is not straightforward. The information for the SDs is hidden in the CLDs, collapsed into links and factors. Extracting stocks, flows and auxiliaries from the CLDs requires further investigation of the links and what they represent. This process may change the number of factors in the system (Binder et al., 2004). Thus, between workshops, we cleaned up the CLDs and met with experts (mainly scientists) that the participants have agreed should be consulted. Thus, the changes to the CLDs, did not go beyond what was agreed during the stakeholders' meetings.

### 3.5.3 Quantification of land-sea interactions

#### *3.5.3.1 Agriculture*

The initial CLD from the Agriculture stakeholders meeting (Figure 72) has 19 variables of which three exogenous (*Climate change*, *Training* and *Demographics*).

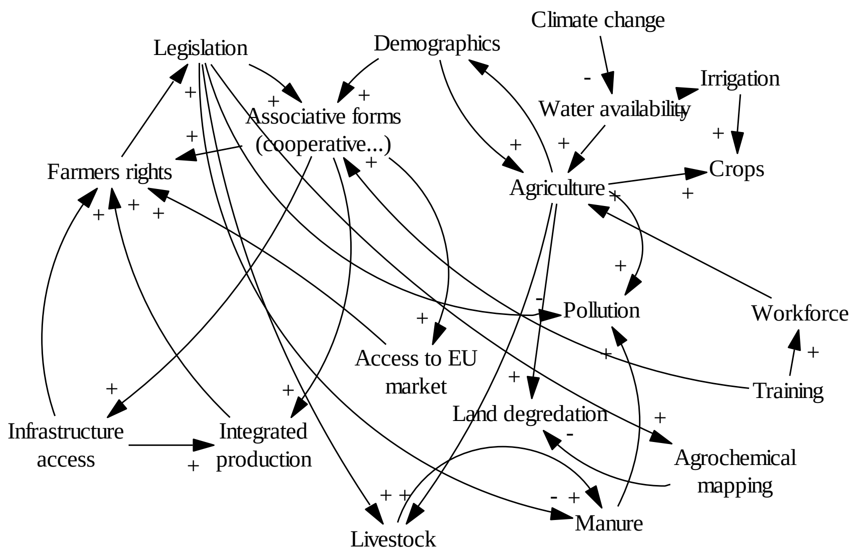


*Figure 72: Initial CLD - Agriculture stakeholders meeting.*

In the CLD to SD translation we identified as stocks *Agriculture*, *Farmer rights, Water availability* and *Pollution.* However, because the meaning of these variables was not consistent with what was intended during the discussions in Romanian, we renamed or redefined some of them. *Agriculture* was considered to be *Agriculture productivity* (based on crop production), Farmer rights was changed to *Farmers welfare* and Pollution was further specified to be *Pollution from Agriculture* as pollution also is considered in other sub-models. Other variable name adjustments were: *Associative forms (cooperative…)* to *Farmers cooperation*, *Access to EU market* to *Access to a wider market*, *Land degradation* to *Soil quality*. Demographics was changed to *Population* and an extra link was added to workforce as population is the main input for *workforce* (Figure 73). According to the model structure the farmers welfare is increased by their cooperation particularly through sharing their assets and integrated production that ensures sustainable agriculture by adjusting agricultural practices and the use of alternatives over time, taking into account new knowledge and new methods. The pollution from agriculture is decreased by the implementation of bio-economy which is meant to reduce the dependence on natural resources, to transform manufacturing, to promote sustainable production of renewable resources from land, fisheries and aquaculture and their conversion into food, feed, fiber, bio-based products and bio-energy, while growing new jobs and industries[8]. But agriculture productivity gains can mean little without improving the access to markets. Market structures are very weak, so the allocative efficiencies that markets achieve in fast-growing sectors of their economies do not materialize. Instead, undeveloped market demand for outputs discourages producers from raising production, while the consequent failures of incomes to rise in rural areas deters private traders and rural enterprises from entering and doing business. In the absence of functioning markets, rural areas remain trapped in a subsistence economy in which neither the narrow agricultural production sector nor the wider rural economy (both of which generate off-farm employment opportunities) can grow (OECD, 2007). Although not specifically mentioned by the stakeholders, the variables *Expenditure* and *Forest belts* were added to the model. The farmers welfare is decreased by the cost of production including raw materials, fertilizers, costs with workforce and investments all considered as expenditure. The forest belts will improve water availability and that this will increase the agricultural productivity. It is to be highlighted that establishment of protective forest belts and increasing the forested area is part of several policy papers in the development of the Danube Mouths region such as Danube Delta strategy, National Regional Development Program etc. The forest belts offer multiple beneficial effects including biodiversity increase, reducing soil erosion, mitigating of flood risks, trapping snow, and increasing crop yields.

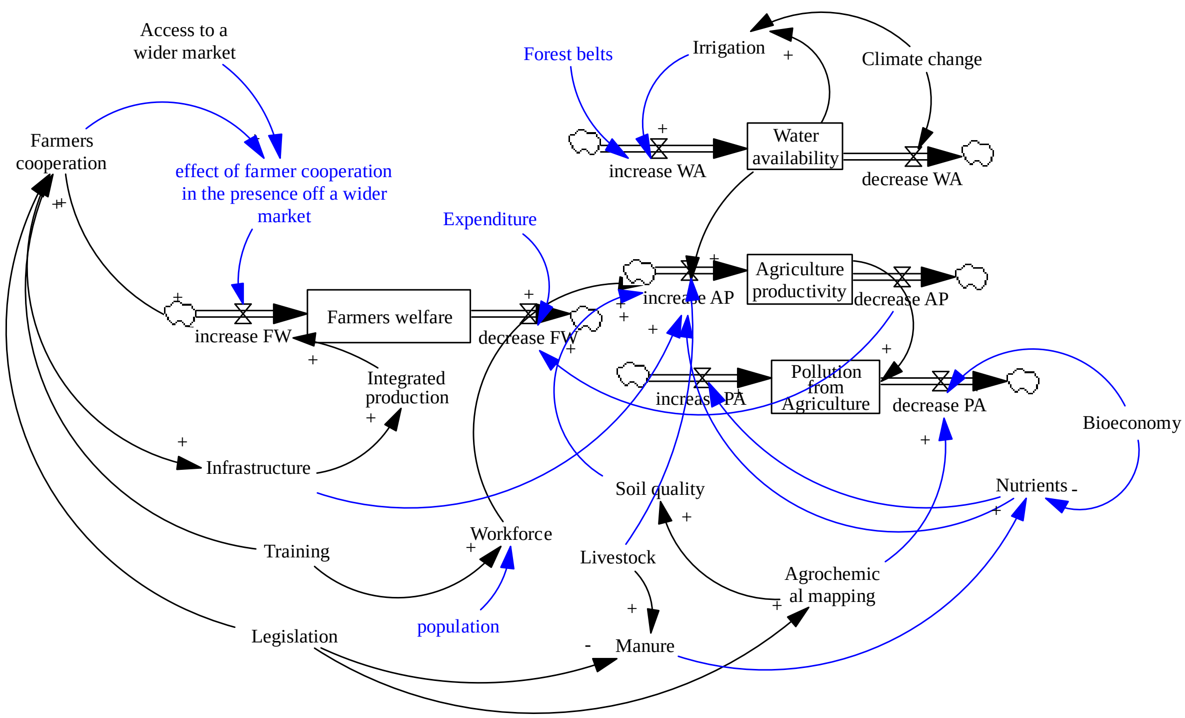


*Figure 73: SD model structure for Agriculture (blue arrows and variables added).*

The sub model drivers/boundaries are given by *Legislation, Bioeconomy, Climate change, Forests belts, Access to a wider market, Population, Livestock, farmers expenditures, and Training*.

[8] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/bioeconomy

#### 3.5.3.2 *Fishery*

The fishery stakeholders' meeting gathered both freshwater (Danube Delta) and marine (Black Sea) fishermen. Even though several issues were common (e.g. legislation, fish market, fishermen welfare, etc.) we chose to separate the model into two types of fish stocks mainly due to the aquaculture topic. Currently aquaculture is relatively developed in the rural area (freshwater) and deficient in the Black Sea, due to the lack of a legislative framework to allow the concession of the coastal waters. Aquaculture is considered one of the future businesses in the Romanian Black Sea. To allow calculating marine aquaculture in future scenarios we therefore also need to add it to the marine fishing model.

Initially, the CLD for the fishery had 18 variables of which 6 were exogenous – climate change; education, training and research; invasive species; legislation; pollution and recreational fishing (Figure 74). By deleting freshwater fish stock, freshwater fisheries, recreational fishing, and tourism (as not being relevant for marine fishery) and due to spatially different areas we achieved the Marine Fishery initial CLD (Figure 75).

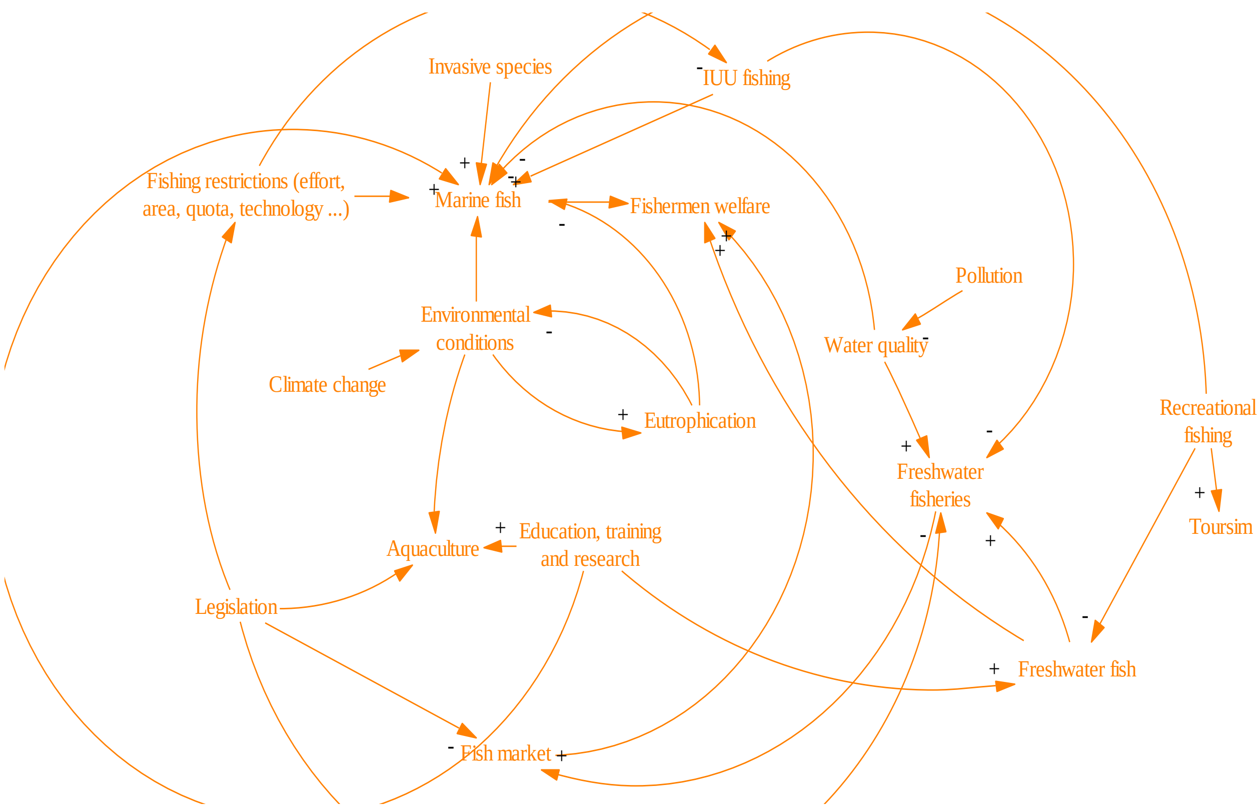


*Figure 74: Initial CLD - Fishery stakeholders meeting.*

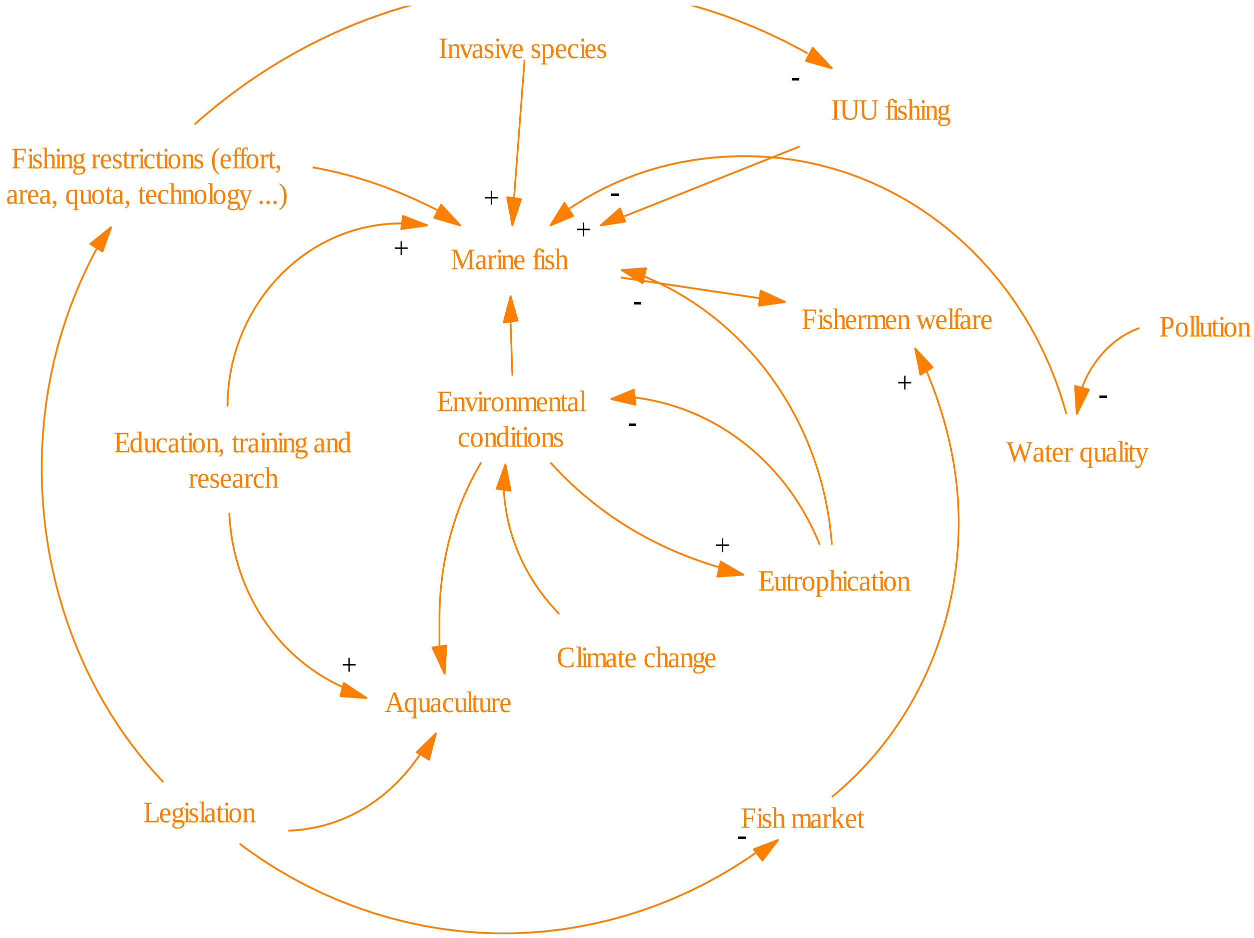


Figure 75: Marine Fishery CLD (from initial).

In the new CLD we found four variables linked to the environmental aspects – *environmental conditions, water quality, eutrophication,* and *pollution*. As water quality and eutrophication, are included in the sub-models for environment, we remove these from the current sub-model. As the general term environmental conditions also appears in other sub-models we rename this variable here to mean the natural characteristics suitable for marine fish and aquaculture (variable marine *environmental conditions*). At this stage, the model structure has two stocks – *Marine fish stock (MFS)* and *Aquaculture* which increase with in- and outflows (increase/decrease marine Fish Stock, increase/decrease aquaculture). A third stock, *marine fishermen welfare,* is added to quantify the net income. *Awareness and marketing* were added as one of the important drivers for an increase of the consumption of aquaculture products. Thus, in our model the marine fish stock's dynamics is dependent on the *Education, training and research* as scientific support for policies and decision makers (*Legislation*) regarding the fishing restrictions. Another important aspect is represented by the illegal fishing (*IUU*) and *Pollution* which are reinforcing the marine fish stock fall. The *marine aquaculture* production and the *marine fish stock* is increased by the *Education, training and research* and the *fish market* as one of the main components of the growing fishermen's welfare (Figure 76).

The sub model drivers are *Climate change, IUU (illegal) fishing, Fishing, Pollution, Awareness and marketing, Legislation* and *Education, training and research*.

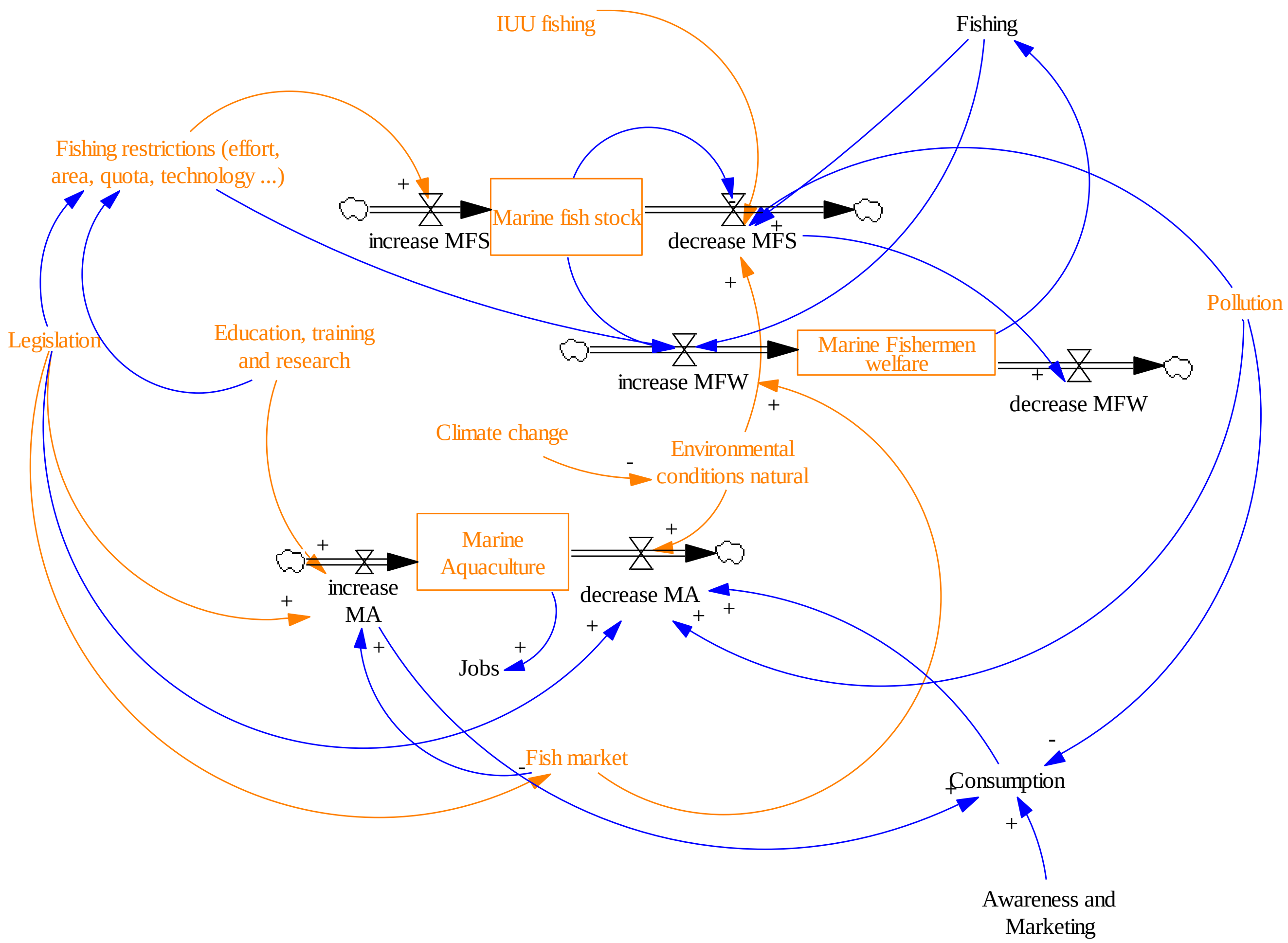


*Figure 76: SD model structure for Marine Fishery (blue arrows and black variables added).*

We obtained the Freshwater fishery's CLD by deleting from the initial one, the *marine fish stock* (Figure 77).

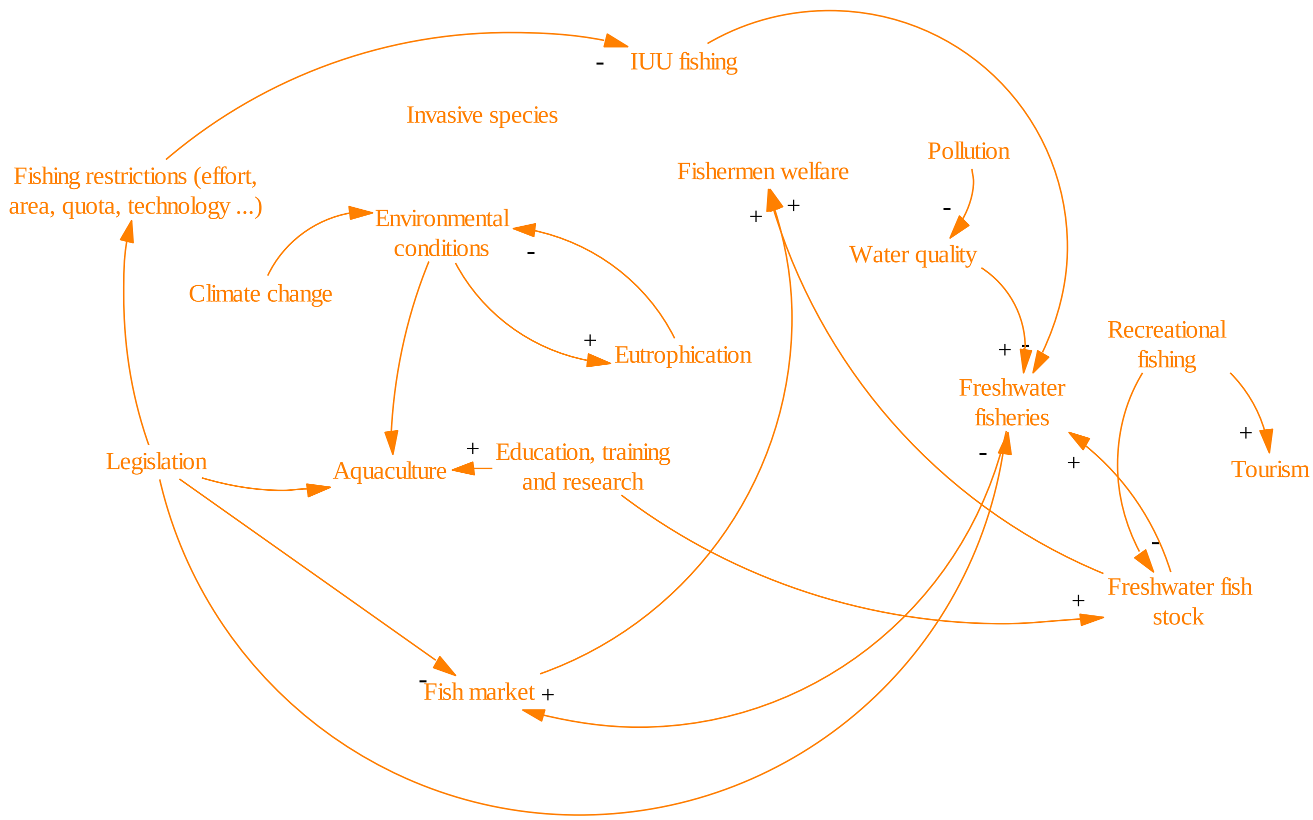


*Figure 77: Freshwater Fishery CLD (from initial).*

Like in the marine fishery model Danube Delta *water quality* and *eutrophication* were included in *Pollution* and as was the case for the marine environment the environmental conditions are in the context of this sub-model restricted to the 'freshwater environmental condition' of the Danube Delta natural characteristics (including the background from the upstream). In this regard, our research (MDRAP, 2016) shows that the water quality, mainly due to the *hydrological changes* into the Danube Delta was one of the reasons that the low economic value fish species (e.g. *Gibel carp*) have proliferated to the detriment of valuable species. This aspect was often discussed by stakeholders referring to *clogged channels*. During the meetings it was considered that clogged channels are only causing water level concerns linked to transportation and tourism. The model structure has three stocks – *Freshwater fishermen welfare*, *Freshwater fish,* and *Freshwater aquaculture* (Figure 78).

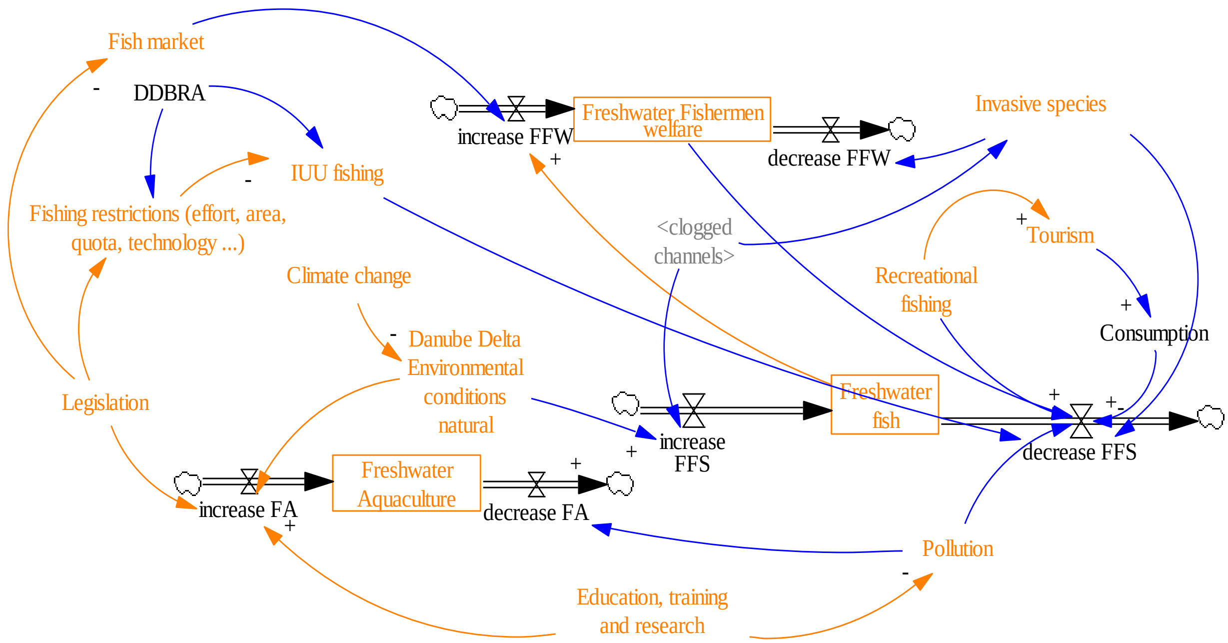


*Figure 78: SD model structure for Freshwater Fishery (blue arrows and black variables added).*

The sub model drivers are *Climate change*, *Danube Delta Biosphere Reserve Administration (DDBRA)*, *Legislation, Education, training and research, Hydrological restoration, Recreational fishing*.

### *3.5.3.3 Tourism*

Two stakeholders' meetings were dedicated to tourism – one for rural (Danube Delta neighborhood) (Figure 79) and the other for coastal (core Danube Delta and Black Sea coastal operators) (Figure 80).

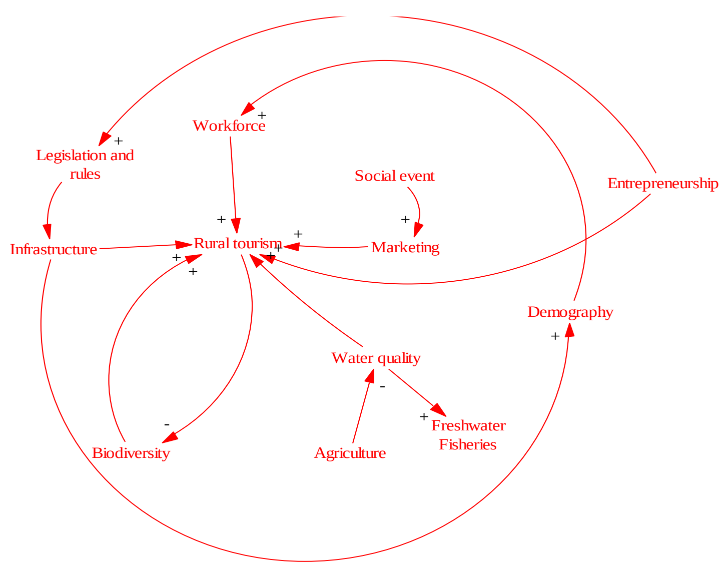


*Figure 79: Initial CLD – Rural tourism stakeholders meeting.*

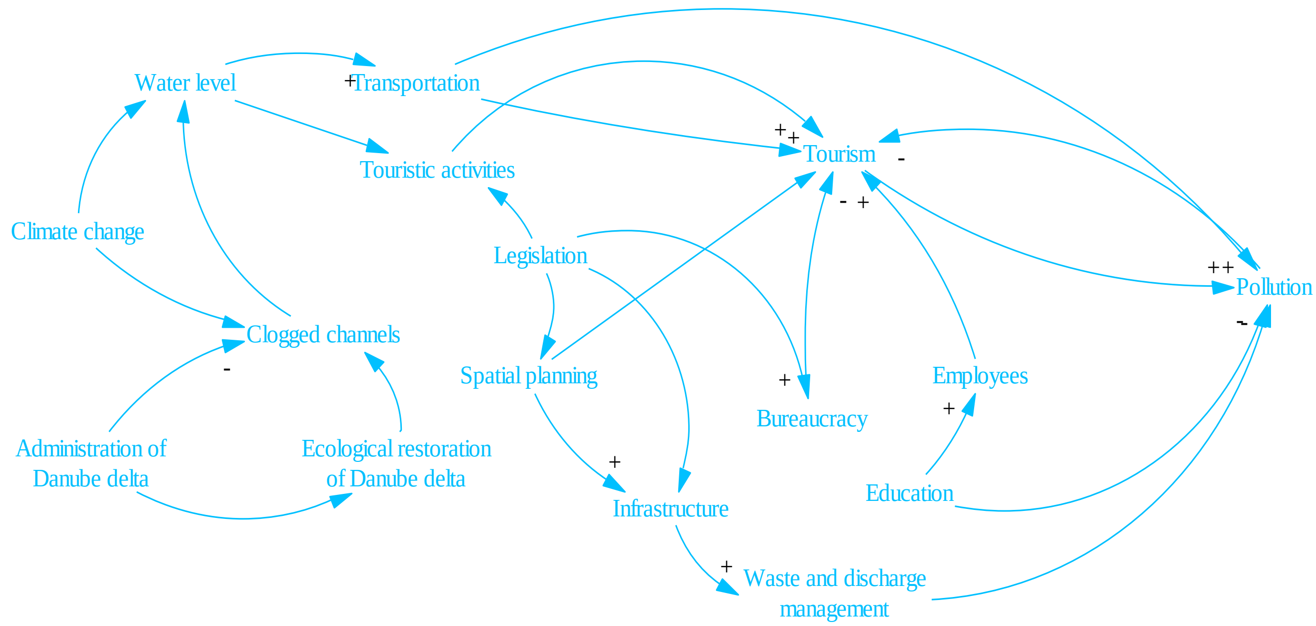


*Figure 80: Initial CLD – Coastal tourism stakeholders meeting.*

The meetings' outputs were similar for the rural and coastal tourism outlining that tourism has significant potential as a driver for growth for the local economy. However, the protected areas restrictions are limiting its growth which is usually accompanied by significant changes. Thus, the need for ecotourism was emphasized, as well as its diversification (*touristic activities*) leading to slow tourism in the benefit of the protected area (*biodiversity*) and local people (*workforce*). Destination planning and development strategies (*marketing*, *social events*) are important steps towards the greening of tourism. The important role of the governance (*legislation and rules*, *administration of the Danube Delta*, *bureaucracy*) and investments (infrastructure) was mentioned in terms of hydrological restoration (*clogged canals*), environmental protection and sanitation (*waste and discharge management*). Although the initial CLDs (Figure 79 and Figure 80) have only one common variable, *infrastructure*, as the main interaction between areas, we merge it into the Tourism CLD which could be applied for coastal Black Sea and core Danube Delta and also its neighboring areas (rural). The merged tourism sub model has the following drivers (yellow boxes)– *Climate change, Education, Administration of Danube Delta, Social events,* and *Entrepreneurship* (Figure 81). Agriculture and freshwater fisheries were deleted as being developed in previous sub models.

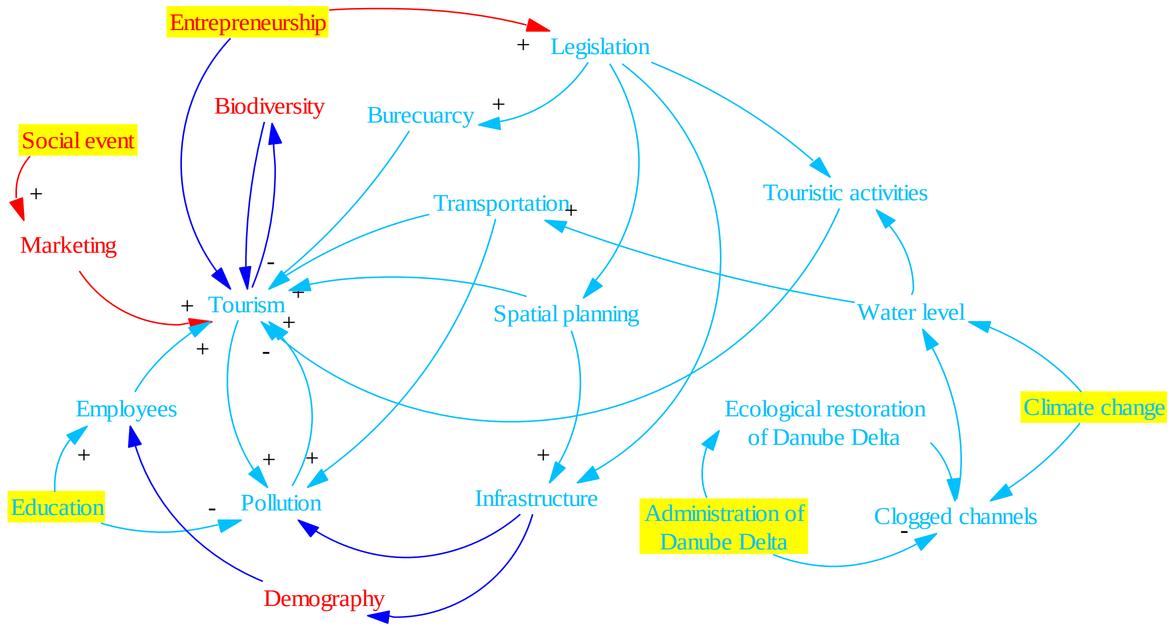


*Figure 81: Tourism merged CLDs.*

The sub-model structure has as main balancing loop *Tourism* ⟶ *Pollution* ⟶ *Biodiversity* ⟶ *Tourism*. Thus, the sub model considers that the increase of tourism has as main consequence the increasing pollution which led to biodiversity decreasing. Once the biodiversity has decreased the area is no more a touristic attraction (Figure 81). Pollution from Tourism, Tourism business development, Biodiversity and Clogged channels stocks in the sub model structure (Figure 82).

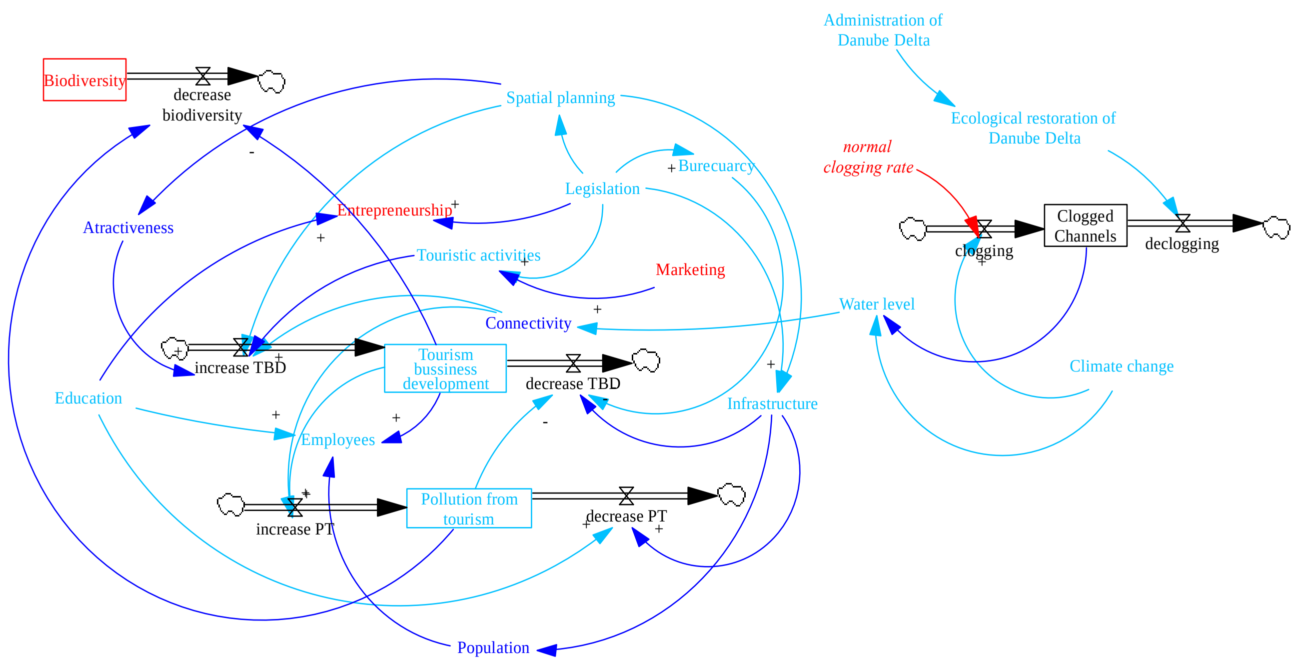


*Figure 82: SD model structure for Tourism.*

The sub model drivers are *Climate change*, *Legislation*, *Administration of the Danube Delta Biosphere Reserve*, *Education, Spatial planning*, *Marketing*.

#### *3.5.3.4 Rural development*

From its initial 21 variables, the *Rural development* CLD (Figure 83) was firstly simplified by excluding the variables which were already included in other sub-models (Agriculture, Fishery, and Tourism) (Figure 84).

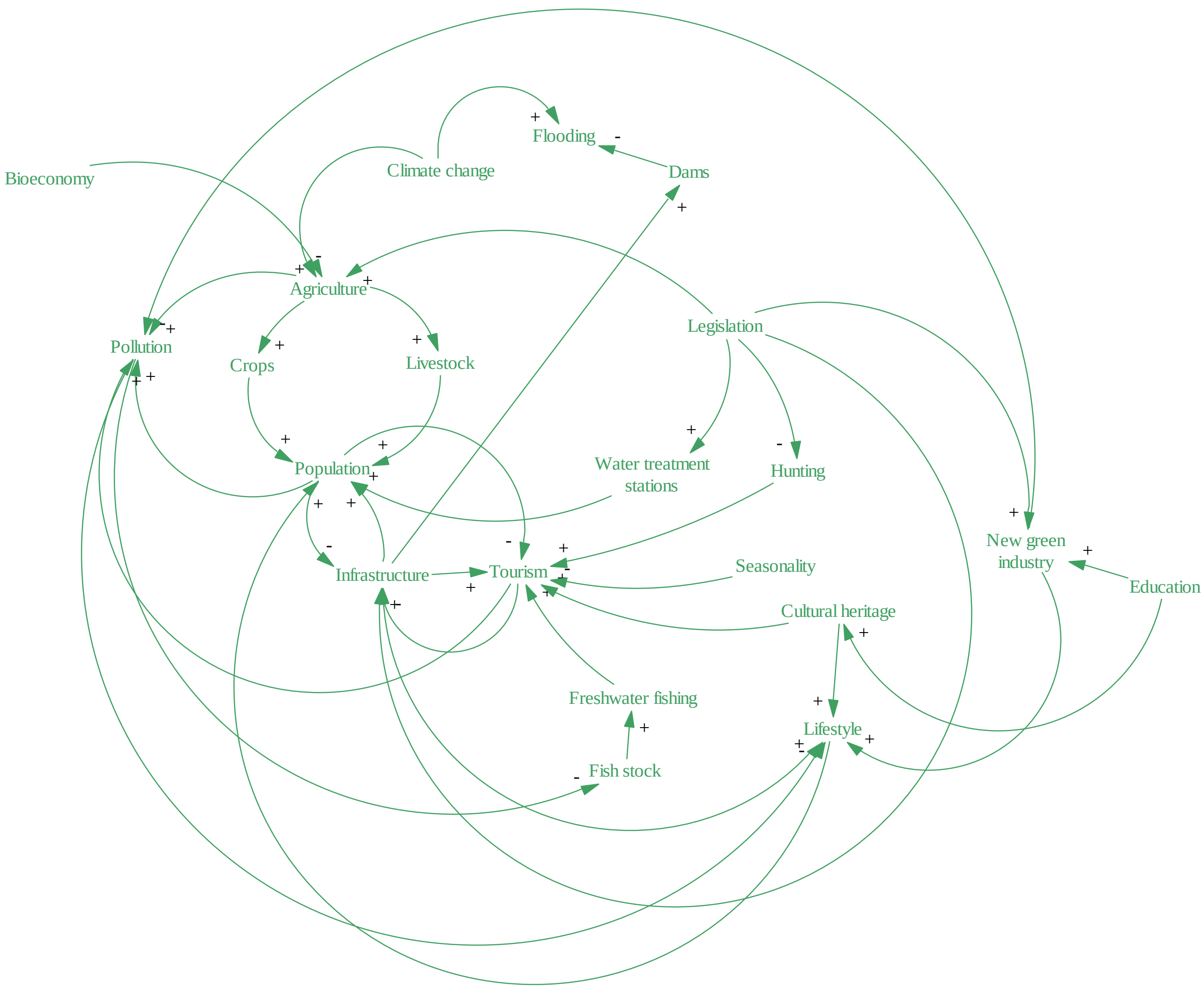


*Figure 83: Initial CLD – Rural development stakeholders meeting.*

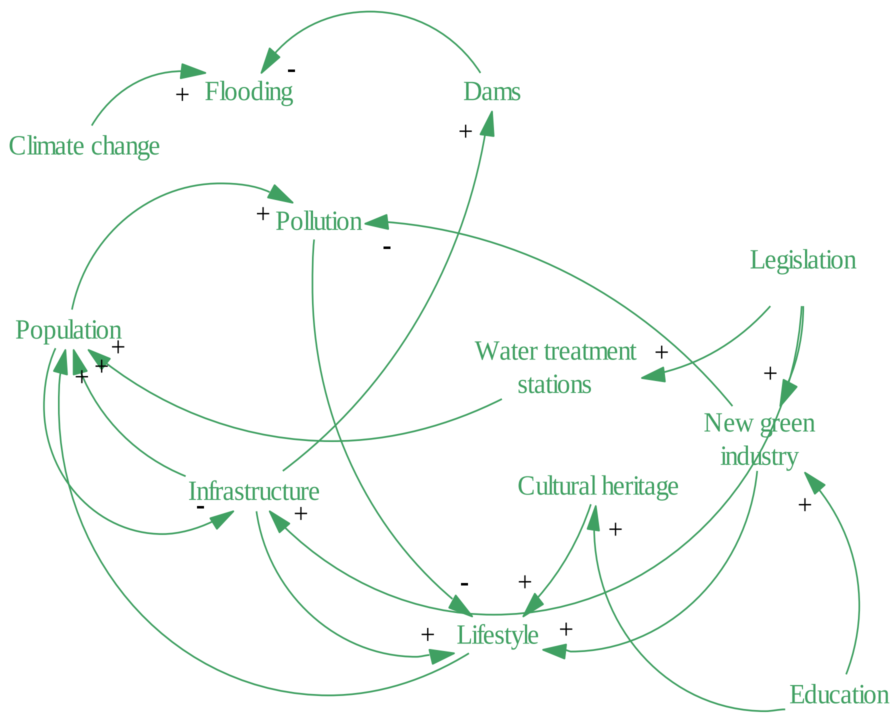


*Figure 84: Rural development CLD after removing discussed variables/sub-models.*

To derive the SD from the rural development CLD, furthermore cleaning of the variables and their relations was performed. The variable *New green industry* was renamed to *rural innovative business* mainly because the stakeholders are not used to using the word "green" in this context. The rationale behind the choice of new name can be explained by going back to the original CLD from the stakeholders meeting, where this variable was originally named "*industrial development*" and it included the non-agricultural business in the rural economy, excluding tourism, such as: circular economy business models, manufacture etc.

The variable *lifestyle* will be used to describe how attractive living in the rural coastal area is. This is like measuring the quality of life. Quality of life is identified in terms of service provision, and it affects the demographics (population): if lifestyle is decreasing, people will want to leave the area and the population will decrease.  This stock is quantified as the availability of healthcare, education, economic opportunities, environmental conditions, human pressure, and the overall accessibility of the areas.

*Pollution from basic services* will be assessed in term of environmental quality of the area. The flow that increase this stock will originate from *infrastructure* (domestic input - wastewater sewage systems, solid waste, water supply). The pollution will decrease by legislation (i.e. recycling, recovery, etc.) and local development strategies and infrastructure's component (water treatment stations). *Infrastructure* and basic services in rural communities of Danube's mouths region are considered inadequate both in terms of quality but especially their functionality. Infrastructure development is an engine in the prosperous economic growth of the rural area being composed of the following components: water treatment stations, healthcare services, connectivity (transportation, ICT), schools (Figure 85).

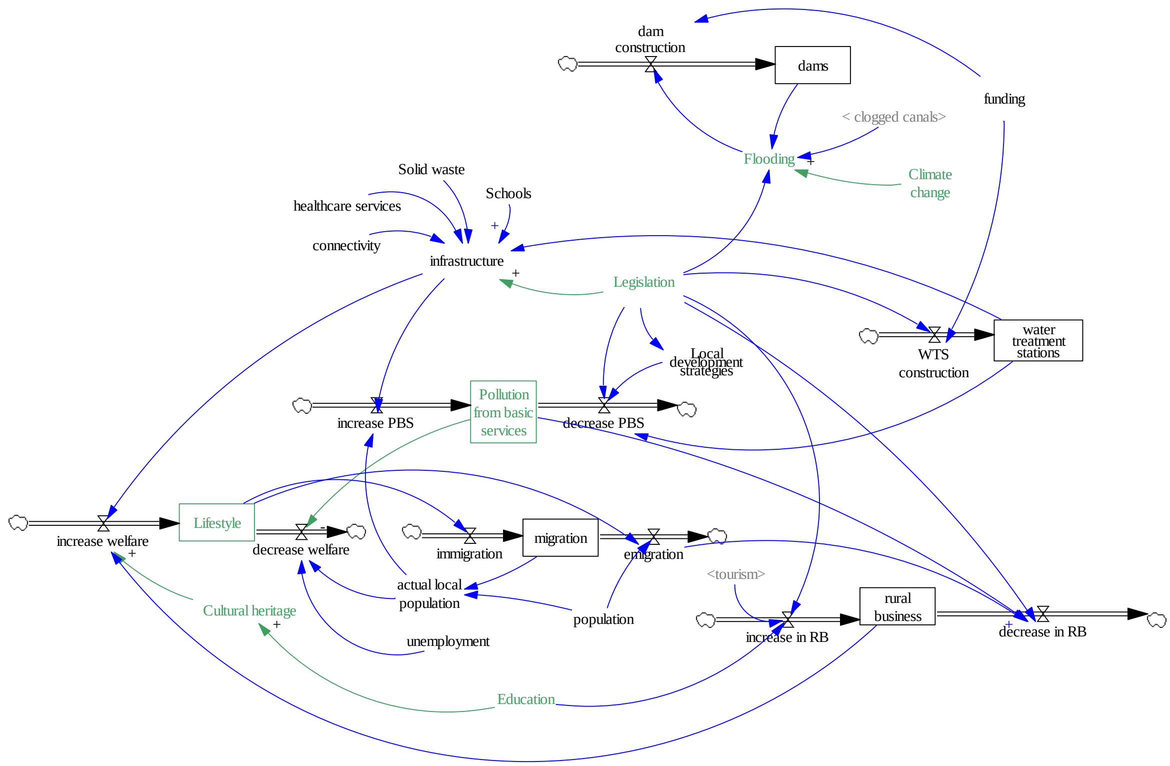


Figure 85: Rural development model structure.

The sub model drivers are *Climate change, Education, Legislation*, *Funding*, *Population,* Basic services (*healthcare services, connectivity, schools, water treatment stations*), *Unemployment*.

### *3.5.3.5 Ecosystem management*

During the stakeholder meetings the ecosystem management and the environmental protection were not specified. However, several variables (e.g. pollution, water quality, biodiversity) are part of more than one sub model. Additionally, one of the strategic objectives of the Danube Delta Strategy is to keep the unique natural values through an environmental management guided by science and by strengthening local communities in the role their proactive protectors of this unique world heritage (MDRAP, 2016). Accordingly, we decided to future develop a new sub model, *Ecosystem management*. It requires maintaining natural capital (water quality, biodiversity) as both a provider of economic inputs and outputs. The protection of natural systems represents not an overarching panacea for achieving economic vitality and social justice, but a necessary component of an entire system for achieving economic, social, and environmental 'sustainability', in which economic reforms and social reforms are as important (Basiago, 1999).

During the process of model structure development, we found several variables linked to the environmental quality or ecosystem management. Accordingly, we developed an Ecosystem management sub model as a connection with the different sub-models from the previous paragraphs. This sub-model structure contains all relevant stocks, flows and auxiliary variables related to the environment. These are further supplemented with some new ones like *Freshwater Quality* and *Black Sea water Quality*, *Low economic fish species*, *Birds*. The *Biodiversity* stock was moved from the Tourism sub model (paragraph 3.5.3.3) as the most important ecosystem service of the Danube Delta Biosphere. In this phase links between sub models were created as shadow variables which refer to variables defined in other sub-models: *Pollution from agriculture*, *Pollution from basic services* and *Pollution from tourism* are inputs for the rate of *decreasing freshwater quality*. We replace the *pollution* from Freshwater Fishery with *Freshwater quality* (shadow variable defined in the freshwater fishery sub-module) and from Marine Fishery with *Black Sea water quality* (shadow variable defined in the marine fishery sub-module) (Figure 86).

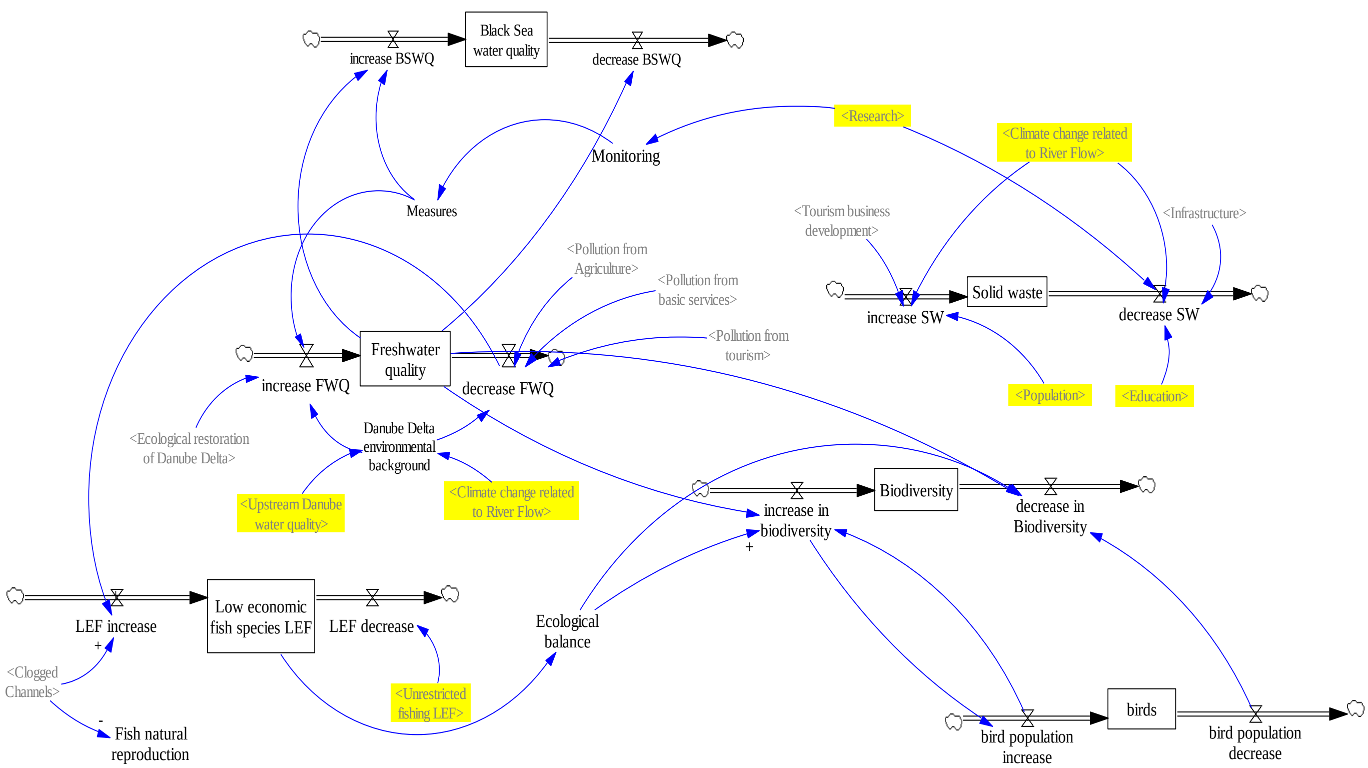


*Figure 86: Ecosystem management sub model.*

All changes resulted in the Vensim sub-model. Accordingly, the *freshwater quality* in the Danube Delta is calculated as function of the *upstream water quality* and *climate change variable related to the river flow*. The freshwater quality it is also improved through *ecological restoration* and management measures taken based on *research* and *monitoring* activities. The water quality in the Danube Delta is deteriorated by pollution from different sectors – agriculture, tourism, and basic services. The water quality is an important input to the increase in biodiversity which is the main ecosystem service of the biosphere reserve. Another important link is with the Black Sea water quality which is significantly influenced by the river's outflow not only due to freshwater but also pollutants (Figure 87 and Table 9).

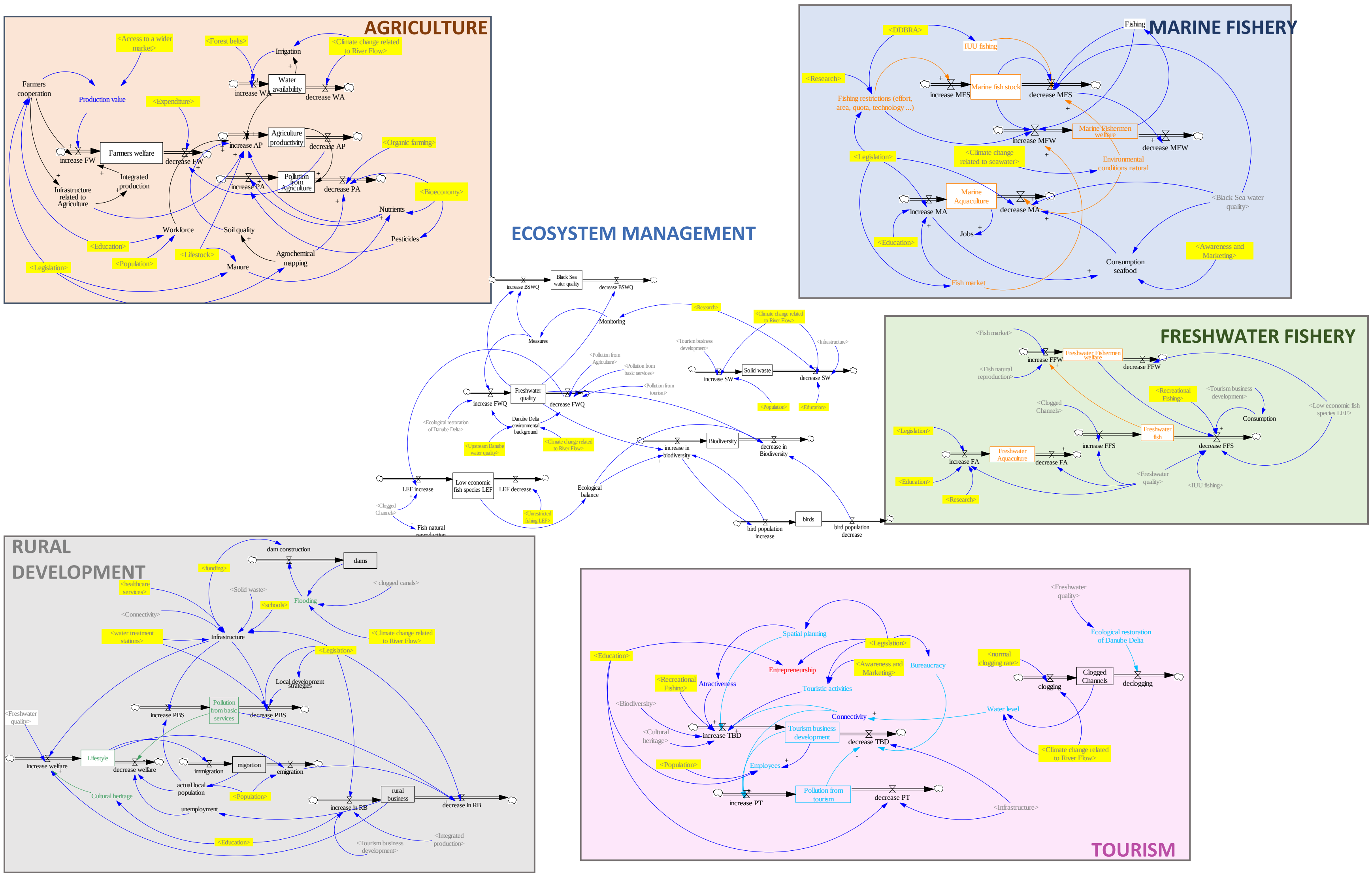


*Figure 87: Integrated sub models stocks and variables, MAL05 (yellow are external inputs).*

### 3.5.4 Problems that can be addressed with the SD models

Overall, the model will tackle issues on how to use the key points of growth within rural areas (that is agriculture, tourism and fishery) to improve the socio- economic state of the area, while conserving the environmental assets. Therefore, the following problems might be addressed upon the stakeholders' requirements.

- How can agriculture contribute to improved management of natural resources (water and soil);
- How climate change is affecting the human economic activity in the rural coastal area?
- Which is the role of financial instruments for rural infrastructure in increasing the quality of life?
- How will the development of services to individuals and of the residential economy affect the freshwater quality?
- How will cooperation help farmers to deal with the economic and environmental challenges?
- How can investment in capacity building (education) bring added value to environmental quality?
- How far can tourism be developed without affecting the biodiversity of the area?
- What effect will the proper management of clogged channels have on economic activities of the area?

The model can help with the following actions of the green deal:

- Assess the impact of using environmentally friendly practices on conservation of biodiversity and improvement of water quality;
- Increase awareness on the importance of activating education and training for a successful ecological transition to efficient use of natural resources and zero waste and pollution.

### 3.5.5 Main model variables

*Table 9: Main variables in the model structure (S: stock, F: flow, A: auxiliary, D: driver)*

| Topic | Name | Unit | Role | Definition |
|---|---|---|---|---|
| 1. Agriculture | Access to a wider market | dmnl | A(D) | expanded access to markets - the core of a more robust agricultural economy |
| | Agriculture productivity (AP) | dmnl | S | Tfp index representing the efficiency of agricultural land, labor, capital, and materials (agricultural inputs |
| | Agrochemical mapping | dmnl | A | soil quality characterization as one of preconditions for good agronomic decision making |

| Topic | Name | Unit | Role | Definition |
|---|---|---|---|---|
| | Bioeconomy | dmnl | A(D) | those parts of the economy that use renewable biological resources from land and sea – such as crops, forest, fish, animals, and micro-organisms – to produce food, materials and energy |
| | Climate change related to River flow | dmnl | A(D) | Floods and Droughts |
| | increase/decrease AP | t/y | F | rate of increasing/decreasing agriculture productivity |
| | increase/decrease FW | RON/y | F | rate of increasing/decreasing farmers welfare |
| | increase/decrease PA | t/y | F | rate of increasing/decreasing pollution from agriculture |
| | increase/decrease WA | t/y | F | rate of increasing/decreasing water availability |
| | Production value | RON | A | Net income from the agricultural production |
| | Expenditure | RON | A(D) | costs of production borne by farmers |
| | Farmers cooperation | | A | an association where farmers pool their resources in certain areas of activity |
| | Farmers welfare (FW) | RON | S | net income of farmers |
| | Forest belts | ha | A(D) | Forest belts as a measure for reduce soil erosion, trap snow, and increase crop yields better than regular shelterbelts, because they are denser and are less likely to have gaps in them |
| | Infrastructure | dmnl | A | An index for the availability of basic physical and organizational structures and facilities (e.g. buildings, roads, power supplies) needed for the operation of a society or enterprise |
| | Integrated production | dmnl | A | alternative methods of coordinating management and control of farm production from farm supplier to ultimate consumer |
| | Irrigation | ha | A | the total area supplied with water to the crops to increase the agricultural output and guarantee its independence from weather conditions |
| | Legislation | dmnl | A(D) | law and rules applicable for agriculture practices to protect the environment and for farmers association |
| | Livestock | individuals | A(D) | all domestic animals raised for production, breeding and draft, domestic use. |
| | Manure | t | A | organic matter (animal feces ) that is used as organic fertilizer in agriculture |

| Topic | Name | Unit | Role | Definition |
|---|---|---|---|---|
| | Nutrients | t | A | compounds that contain nitrogen and phosphorus which are generally not toxic at the concentrations typically found in nature, however they can have a large impact on the health of rivers, estuaries, and sea by encouraging excessive algal growth. They are the main cause of the eutrophication. |
| | Pollution from Agriculture (PA) | t | S | quantity of pesticides applied in the agriculture |
| | Population | individuals | A(D) | all persons who have their usual residence in the studied area |
| | Soil quality | | A | capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity |
| | Education | individuals | A(D) | number of vocational schools' graduates |
| | Water availability | t | S | water quantity available for irrigation and livestock production |
| | Workforce | individuals | A | number of employees in agriculture |
| 2. Marine Fishery | Awareness and Marketing | dmnl | A(D) | awareness and marketing channels and campaigns for aquaculture products consumption acceptance |
| | Climate change related to seawater | ºC | A(D) | Seawater temperature |
| | Consumption seafood | t | A | aquaculture products consumption |
| | Increase/decrease MA | t/y | F | rate of increasing/decreasing of marine aquaculture biomass |
| | Increase/decrease MFW | RON/y | F | rate of increasing/decreasing of marine aquaculture biomass |
| | Increase/decrease MFS | t/y | F | rate of increasing/decreasing of marine aquaculture biomass |
| | Education, training and research | RON | A | funds for knowledge based on scientific support for marine fishery activities |
| | Environmental conditions natural | dmnl | A | background (natural variability) Black Sea water quality |
| | Fish market | t | A | wholesale fish market facility |
| | Fishing | t | A(D) | annually total fish capture (Black Sea) from the studied area |
| | Fishing restrictions | dmnl | A | Regulation limiting unwanted catches, juvenile fish or endangered species |
| | IUU fishing | t | A(D) | Illegal, unreported and unregulated (IUU) fishing is a broad term that captures a |

| Topic | Name | Unit | Role | Definition |
|---|---|---|---|---|
| | | | | wide variety of fishing activity. IUU fishing is found in all types and dimensions of fisheries; it occurs both on the high seas and in areas within national jurisdiction |
| | Jobs | employees | A | number of employees from the marine fishery sectors |
| | Legislation | dmnl | A | law and rules applicable for fishery development and environmental (fish) protection |
| | Marine Aquaculture (MA) | t | S | annually (Black Sea) production from fish and shellfish farming |
| | Marine fish stock (MFS) | t | S | fish biomass available for fishing in the studied area |
| | Marine Fishermen welfare (MFW) | RON | S | net income of marine fishermen |
| 2. Freshwater Fishery | Climate change related to River flow | dmnl | A(D) | Floods and Droughts |
| | Consumption | t | A | Quantity of fish consummated by one person (annually average) |
| | Upstream Danube water quality | dmnl | A(D) | Index of Danube's water quality (the upstream waters entering in Danube Delta) |
| | Increase/decrease FA | t/y | F | rate of increase/decrease of freshwater aquaculture |
| | Increase/decrease FFS | t/y | F | rate of increase/decrease of freshwater fish stock |
| | Increase/decrease FFW | RON/y | F | rate of increase/decrease of freshwater fishermen welfare |
| | Freshwater Aquaculture (FA) | t | S | Production of freshwater aquaculture |
| | Freshwater fish (FFS) | t | S | Freshwater fish stock |
| | Freshwater Fishermen welfare (FFW) | RON | S | Income of freshwater fishermen |
| | IUU fishing | t | A | Same as in marine fishery |
| | Legislation | dmnl | A(D) | law and rules applicable for agriculture practices to protect the environment and for fishermen |
| | Recreational fishing | t | A(D) | annual fish capture in a recreational scope |
| | Research | RON | A(D) | funds for knowledge based on scientific support for freshwater fishery activities |
| 3. Tourism | DDBRA | dmnl | A(D) | Danube Delta Biosphere Reserve Administration |
| | Attractiveness | individuals | A | Returning tourists |
| | decrease biodiversity | Species/y | F | Rate of decreasing of number of species |

| Topic | Name | Unit | Role | Definition |
|---|---|---|---|---|
| | Increase/decrease PT | t/y | F | Rate of increasing/decreasing of Pollution from Tourism |
| | Increase/decrease TBD | RON/y | F | Rate of increasing/decreasing of Tourism Business |
| | Employees | individuals | A | Number of employees in tourism sector |
| | Entrepreneurship | dmnl | A | Number of accommodation units |
| | Legislation | dmnl | A | law and rules applicable for practices to protect the environment from tourism activities |
| | Pollution from tourism | t | S | quantity of pollution generated by tourism |
| 4. Rural development | Climate change related to river flow | dmnl | A(D) | Floods and Droughts |
| | Increase/decrease PBS | t/y | F | Rate of increasing/decreasing pollution from basic services |
| | Increase/decrease welfare | RON/y | F | Rate of increasing/decreasing of population's welfare |
| | Education | dmnl | A(D) | Level of education for population |
| | Legislation | dmnl | A(D) | law and rules applicable for sustainable development |
| | Pollution from basic services (PBS) | t | S | quantity of pollutants (N, P, CBO5, solid waste) generated by the doemstic population |
| | Schools | dmnl | A(D) | Number of schools |
| | unemployment | individuals | A | Number of people without an workplace |
| 5. Ecosystem management | Black sea water quality | dmnl | S | Index of Black sea water quality |
| | Biodiversity | dmnl | S | Total number of species in the area |
| | Birds | dmnl | S | Total number of birds species in the area |
| | Freshwater quality | dmnl | S | Index of freshwater quality |
| | Low economic fish species | t | S | Species proliferated as invasive species or resilient to the pollution |
| | Solid waste | t | S | Solid waster generated by locals and tourists |
| | Increase/decrease of biodiversity | dmnl | F | Rate of biodiversity increasing/decreasing |
| | Increase/decrease of birds | dmnl | F | Rate of birds number increasing/decreasing |
| | Increase/decrease of freshwater quality | dmnl | F | Rate of freshwater quality increasing/decreasing |
| | Increase/decrease | t/y | F | Rate of low economic fish stock |

| Topic | Name | Unit | Role | Definition |
|---|---|---|---|---|
| | of low economic fish stock | | | increasing/decreasing |

### 3.5.6 Data sources


Baboianu G. (2016) Danube Delta: The Transboundary Wetlands (Romania and Ukraine). In: Finlayson C., Milton G., Prentice R., Davidson N. (eds) The Wetland Book. Springer, Dordrecht.

Basiago, A., (1999). Economic, social, and environmental sustainability in development theory and urban planning practice. The Environmentalist 19, 145-161.

Collste, D., Pedercini, M. & Cornell, S.E. (2017). Policy coherence to achieve the SDGs: using integrated simulation models to assess effective policies. Sustain Sci 12, 921–931. https://doi.org/10.1007/s11625-017-0457-x.

Institutul Mational de Cercetare-Dezvoltare Martina “Grigore Antipa” (2018). Studiu privind elaborarea raportului privind starea ecologică a ecosistemului marin Marea Neagră conform cerinţelor art. 17 ale Directivei Cadru Strategia pentru mediul marin (2008/56/EC).

Ministerul Dezvoltării Regionale și Administrației Publice (MDRAP), (2016). Strategia Integrată de Dezvoltare Durabilă a Deltei Dunării.

OECD, (2007). Promoting Pro-Poor Growth. POLICY GUIDANCE FOR DONORS.

https://www.oecd-ilibrary.org/docserver/9789264024786-en.pdf?expires=1595506959&id=id&accname=guest&checksum=1181168B0D5F1115C4F91D0AB20CE3F9.

Petrisor, A.-I., Petre, R., Meita, V. (2016). Difficulties in achieving social sustainability in a biosphere reserve. INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE Volume 7, Issue 1, January-March 2016: 123-136.

Sbarcea, M., Petrisor, A-I, Petrisor, L.E., (2019) Mapping Potential Environmental Conflicts in the Danube Delta Biosphere Reserve. Scientific Annals of the Danube Delta Institute, Vol.24, https://doi.org/10.7427/DDI.24.19

Vaidianu, N., Adamescu, C., Wildenberg, M., Tetelea, C. (2014). Chapter from book Fuzzy Cognitive Maps for Applied Sciences and Engineering (pp.355-374) Understanding Public Participation and Perceptions of Stakeholders for a Better Management in Danube Delta Biosphere Reserve (Romania). 10.1007/978-3-642-39739-4_19.

World Bank (2014a) REPORT 2.2 Draft Danube Delta Integrated Sustainable Development Strategy (2030), https://www.mlpda.ro/userfiles/delta_dunarii/draft_Danube_Delta_Strategy.pdf

World Bank (2014b) DIAGNOSTIC REPORT Danube Delta Integrated Sustainable Development Strategy.

### 3.5.7 Planning

#### *3.5.7.1 Blue Growth sub-model.*

Most of the already discussed sub-models (Agriculture, Fisheries, Rural Tourism, Pollution) or variables (Clogged channels, Water quality, Invasive species) could be found in the initial Blue Growth's CLD (Figure 88). There are only a few unmentioned ones so far like Windfarm, Oil and gas, Shipping (Figure 89). Of these, as a next step we propose to incorporate (parts of) the Wind farm model that is developed in MAL01.

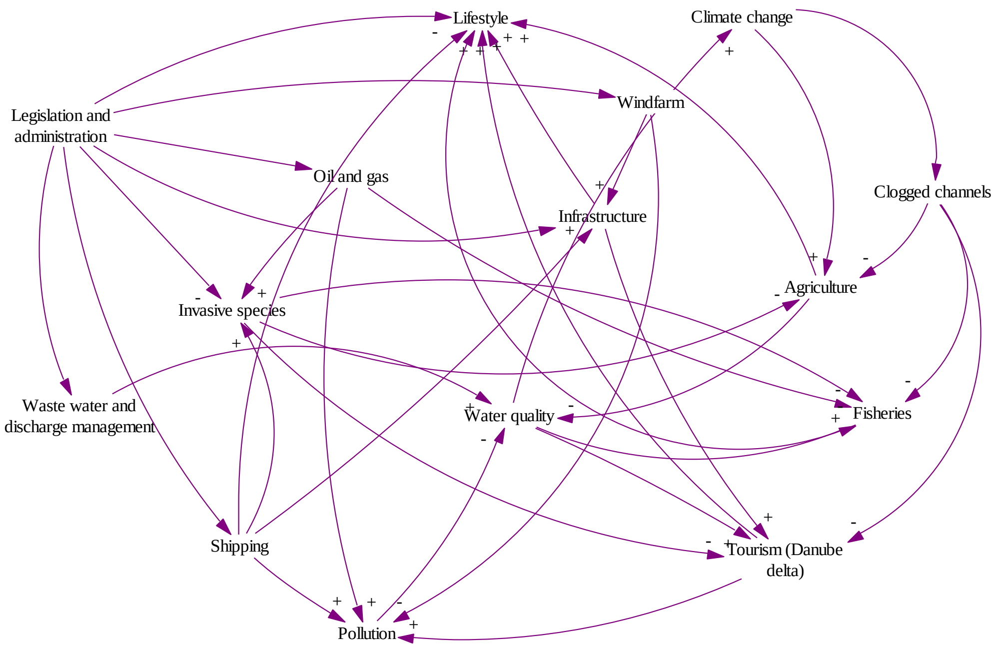


*Figure 88: Initial CLD – Blue Growth stakeholders meeting.*

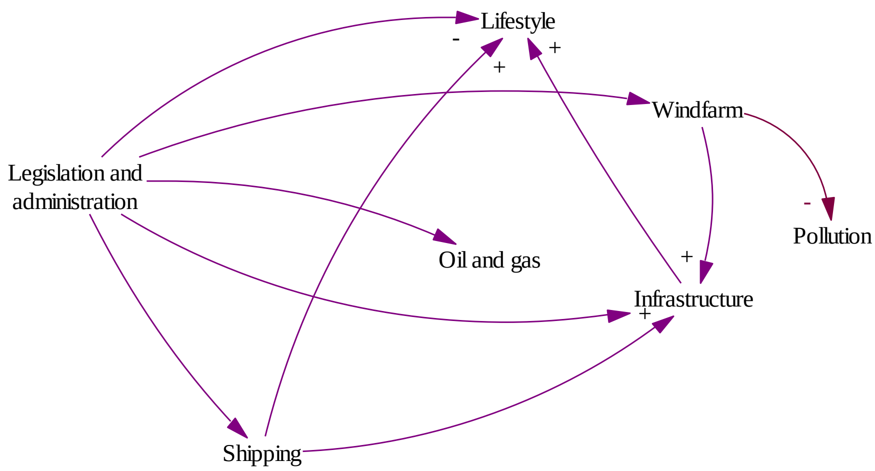


*Figure 89: Blue Growth CLD after removing discussed variables/sub-models.*

The EU is committed to promote offshore wind development and explore the potential of offshore wind in Europe's seas and along its coasts while respecting the ecological limits of natural resources and the interests of other sea users[9]. There are no offshore windfarms in the Romanian Black Sea. This unexploited potential is currently being considered, particularly in the frame of the European Green Deal roadmap so, we plan to take advantage of the MAL01 experience with the windfarm model and adapt this to the Black Sea situation.

#### 3.5.7.2 Next steps in general

In general the following actions are planned in MAL05:

- To develop the sub models and the integrated model by adding some variables upon their availability. For example – ecological restoration of Danube Delta it is a variable which might quantified in different ways like *fish natural reproduction* or *fish migration routes*.
- To make the pilot model operational and prepare preliminary results to be discussed with the stakeholders. During these steps the model will not be thoroughly validated (yet) but testing will be done to ensure that results can be explained by model structure and inputs.
- To organize additional stakeholders meetings where results of the model can be shown and discussed.
- To fine-tune and extend the model considering the stakeholders feedback and requirements.
- To determine the model validity by means of qualitative and quantitative testing, focusing on the model structure, simulated dynamic behaviour of the systems as a whole, and policy or business implications.

[9] https://ec.europa.eu/energy/topics/renewable-energy/onshore-and-offshore-wind_en

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

### 3.6.1 Problem scope of the land sea system

The Mar Menor coastal lagoon (135 $km^2$) 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, development of sustainable business cases based on public-private collaboration, efficient use of water, 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 $km^2$ and is mainly covered by intensive irrigated agricultural and tree crops (Figure 90).

*Figure 90: Cropland area in the Campo de Cartagena near the Mar Menor lagoon (Author: Javier Jiménez).*

The intensive and highly profitable irrigated agriculture mainly 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, sediments and other forms of 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, salt pans and fisheries affecting natural ecological values and socioeconomic sustainability on the other side.

The need to move towards sustainable modes of agriculture 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, and to a lesser extent due to insufficient urban waste water treatment and historic mining activities in the area. 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. Public administrations are not being successful in controlling the implementation of best agricultural practices and there is a general lack of support of touristic activities by the local and regional governments. This favours the uncontrolled development of agriculture leading to the ecological collapse of the Mar Menor lagoon. This crash is negatively affecting the attractiveness and touristic potential of the area and impoverishing local communities.

Following the outcomes of the sectoral and multi sector stakeholder workshops, the main land sea interactions we will consider in the model are:

- The export of nutrients to the lagoon from the catchment area (Campo de Cartagena) by irrigated agriculture due to excessive use of fertilizers and lack of mitigation measures, which causes the degradation of the Mar Menor lagoon and has negative impacts on tourism and local populations;
- The potential for the development of ecotourism and solar photovoltaic energy production facilities and its effect on job creation and recreation activities in the rural and coastal areas.

### 3.6.2 From Multi actor analysis to modelling

Figure 91 shows a high level mind map of the main land-sea interactions identified during the sector and multi sectoral workshops. Some examples of main topics discussed during the stakeholder workshops were in relation to different variables, such as intensive agriculture, social wellbeing (mainly dependent on number and quality of jobs), eco- and agrotourism, sustainable agricultural practices, participatory governance, climate change, lagoon water quality (as a proxy of ecological status), environmental social awareness, the promotion of renewable energy facilities and the tourism seasonality.

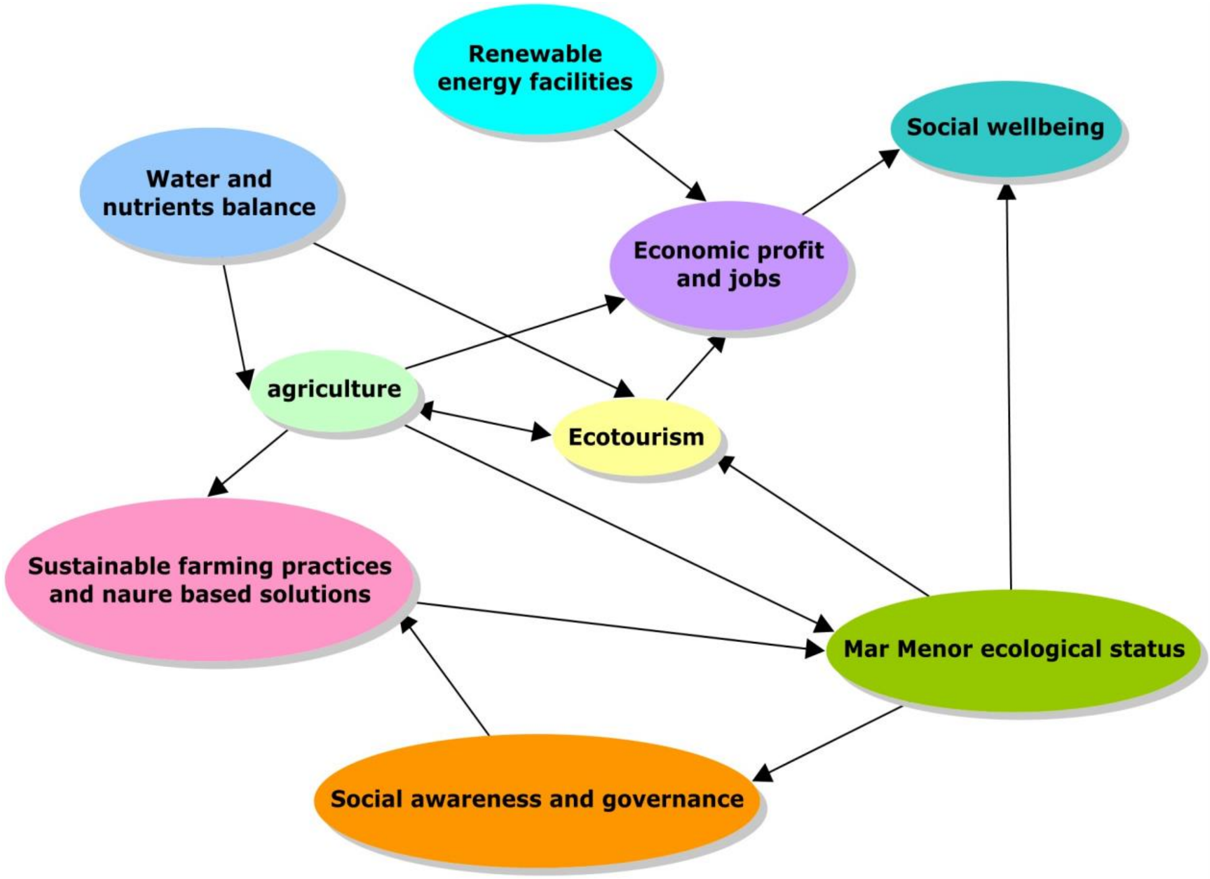


*Figure 91: High level Mind Map of the MAL6 based on the stakeholder workshops.*

Some typical **land-sea system interactions** for the region, identified during the sector and multi sectoral 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;
- Decrease in recreational opportunities for tourists and for local populations living around the Mar Menor lagoon due to poor water quality;
- 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.

In Figure 92 we show the full CLD for MAL6. Although the complexity and size of the CLD makes the figure illegible at this scale, it is clear that directly converting the whole CLD into a corresponding system dynamics model is not feasible. So, instead of attempting to address all the problems outlined in the overall CLD in one single SD model we have identified a number of partial problem domains based on the interaction categories identified by stakeholders and listed above. In the next chapters we define SD models for each of these problem domains. Each of the next chapters starts with the model scope and the CLD that corresponds to that model scope and then converts this information step by step into an SD model structure.


*Figure 92: Full CLD reported by WP1 for MAL6. Red and blue arrows represent negative and positive relationships, respectively.*

Feedback loops are of special interest in SD modeling since they can explain complex relations between variables and synergies and trade-offs between different sectors. One of the main feedback loops identified in the CLD that has driven the design of the SD model is the feedback between Mar Menor water quality, environmental awareness, effectiveness of governance and the reduction of nutrients input to the Mar Menor lagoon via effectively controlling fertilizer use by public administrations (Figure 93).

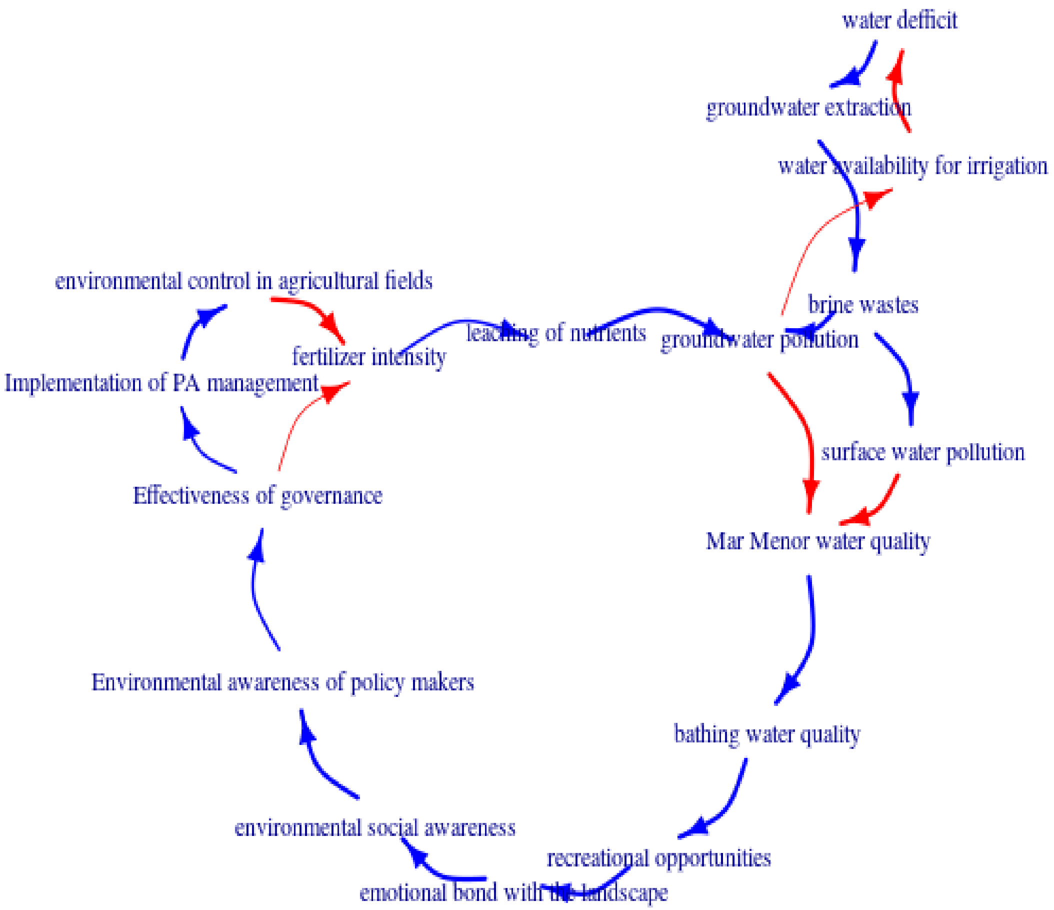


*Figure 93: Excerpt from the CLD showing several loops. Red and blue arrows represent negative and positive relationships, respectively.*

The CLD also shows how effectiveness of governance is a potential driver of another feedback loop since effectiveness of governance is expected to be a disincentive for intensive agricultural activity and support the promotion of inland tourism activities, such as agrotourism and ecotourism, which would enhance recreational opportunities and raise environmental awareness (Figure 94).

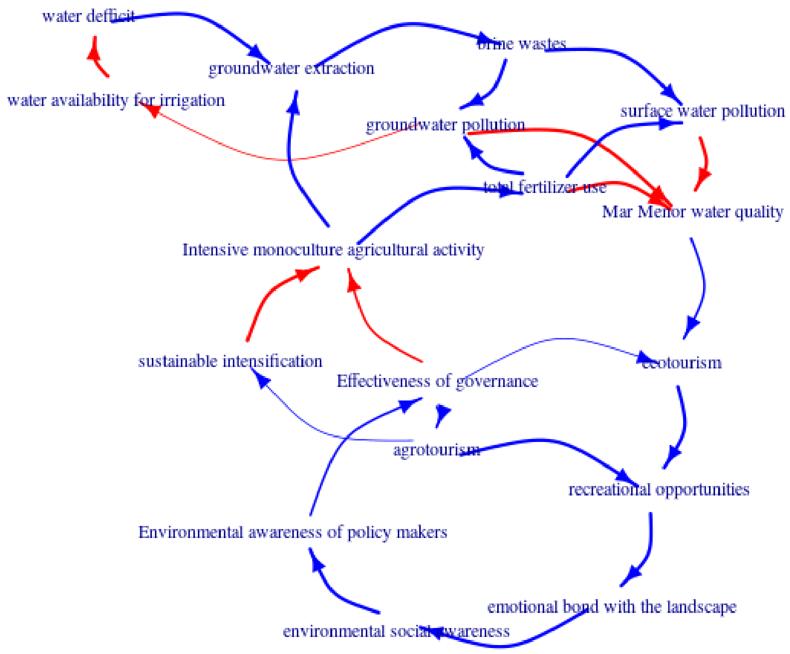


*Figure 94: Excerpt from the CLD showing several loops. Red and blue arrows represent negative and positive relationships, respectively.*

Moreover, a good ecological status of the Mar Menor lagoon, thereby harbouring higher biodiversity and endemic species, would have an indirect effect on social environmental awareness and effectiveness of governance, which would promote sustainable coastal recreational activities, such as scuba diving and sailing, and regulate harmful activities, such as motor boats (Figure 95).

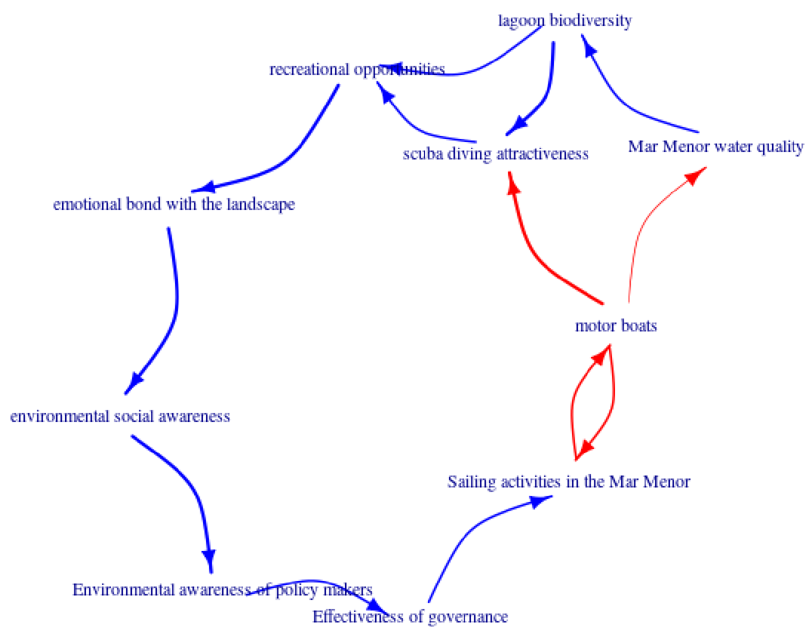


*Figure 95: Excerpt from the CLD showing several loops. Red and blue arrows represent negative and positive relationships, respectively.*

In the next sections we present in detail how we developed the SD models of the interactions between different sectors of the Mar Menor and campo de Cartagena area based on the initial CLD developed with stakeholders during the sectoral and multisectoral workshops. Models that are considered structural are referred to as model sectors and models that are adding new functionalities coupled to the structural models are referred to as model add-ons. All model sectors and add-ons presented in this report are linked and share the same model temporal and spatial boundaries: the Campo de Cartagena catchment linked to the Mar Menor lagoon from 1961 until 2100 on a yearly basis. The sub-models we describe in the next paragraphs are:

- Model sector on agricultural water balance
- Model sector on agricultural nutrients balance
- Model sector on sectorial development and economic profit
- Model sector on Mar Menor degradation
- Model add-on on coastal-rural recreation potential
- Model add-on on social awareness and governance
- Model add-on on sustainable land management practices

### 3.6.3 Pilot model sector 1 design: Agricultural water balance

During the sectoral and multi actor stakeholder workshops no technical information was given about the agricultural water balance but it was pointed out that the water balance was central to study and understand the sustainability of the system in term of water resources use and potential of agriculture. Given the structural water scarcity in the region, the high amount of groundwater extraction, together with the opening of the Tagus-Segura water transfer were mentioned as the main drivers of the expansion of irrigated agricultural areas.

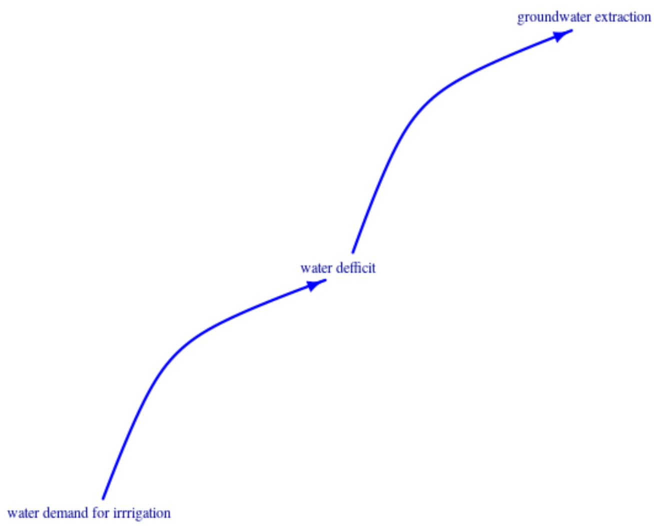


*Figure 96: Excerpt from the CLD related to agricultural water balance. Blue arrows represent positive relationships.*

### 3.6.3.1 Model scope of Agricultural water balance

This model sector characterizes the agricultural water balance in the Mar Menor catchment, which represents around 85% of the total water consumption in this area, and how the available water for irrigation determines to a large extent the potential expansion of irrigated crops. The water demand is driven by the expansion of irrigated land areas. The model sector includes some scenarios (variables in green colour) in relation to climate change and some regulatory management actions proposed by the regional and national authorities.

### 3.6.3.2 Quantification of Agricultural water balance

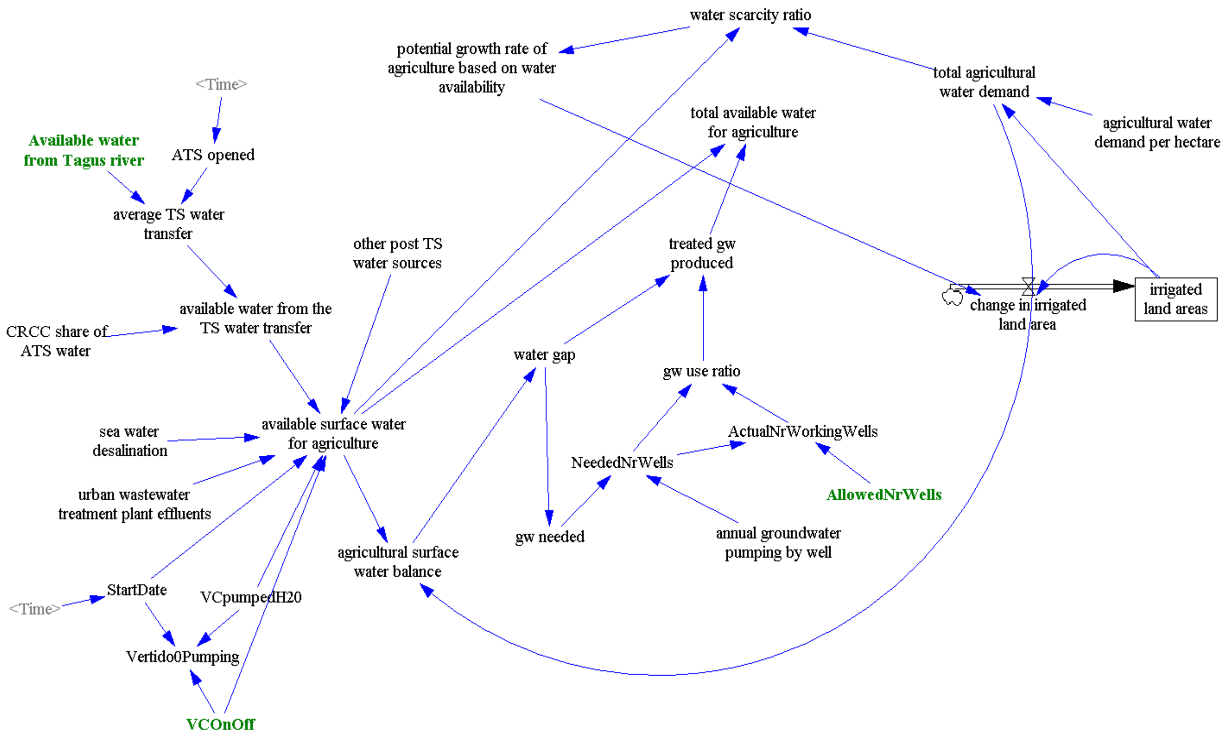


*Figure 97: SD model structure for the agricultural water balance sector. Green colour variables represent main scenarios.*

In the SD model of the agricultural water balance we included all variables that determine the water demand from agriculture and water supply from all different sources. As indicated in the CLD, the groundwater extraction is calculated based on the water deficit. *ATS opened* is a binary variable that becomes 1 in 1979 when the Tagus-Segura (TS) water transfer was opened. The *available water from the TS water transfer* is obtained by multiplying the *average TS water transfer* by the *Comunidad de Regantes del Campo de Cartagena (CRCC) share of ATS water*. The *available water from Tagus river* is constant for the historical period covered by the model (using the yearly average) but can be changed to create future scenarios of climate change based on existing literature that gives estimates for the RCP4.5 and RCP8.5 projections and how these change the water available for transfer between the Tajo and Segura catchment.

The available surface water for agriculture is the sum of: (1) the *available water from the TS water transfer*, (2) *other post TS water sources*, (3) the *sea water desalination*, (3) *urban wastewater treatment plant effluents* and eventually (4) the additional water extracted from the aquifer when/if the Vertido Cero (VC) Plan starts (*VCpumpedH20*). The VC plan will be eventually launched by the National government and aims to extract polluted water from the aquifer, clean it and give it back to farmers for irrigation at an agreed price.

The *total agricultural water demand* is calculated by multiplying the *agricultural water demand per hectare* by the *irrigated land areas* (in hectares). The *agricultural surface water balance* is computed by subtracting the *total agricultural water demand* from the *available surface water for agriculture*.

The *water gap* is zero if the *agricultural surface water balance* is positive and otherwise it corresponds to its absolute value. The *groundwater (gw) needed* is a function of the *water gap* and it is used to calculate the *NeededNrWells* by dividing it by the *annual groundwater pumping by well (the model considers an average value for all wells)*. The *ActualNrWorkingWells* corresponds to the *NeededNrWells* unless this is higher than the *AllowedNrWells*, which is then the final maximum value assigned. *AllowedNrWells* acts here as a scenario in which the *number of allowed wells* (or the corresponding allowed water pumped) can be established by regulations (by default the value is unlimited in the model). The *gw use ratio* is computed by dividing the *ActualNrWorkingWells* by the *NeededNrWells*.

The *total available water for agriculture* is the sum of the *available surface water for agriculture* and the *treated gw produced*. It is not used in the model but it serves as an important indicator of agricultural water consumption. However, the *water scarcity ratio* is only a function of the *available surface water for agriculture* and the *total agricultural water demand*. It is zero if the *available surface water for agriculture* is higher than the *total agricultural water demand* and otherwise equals to the *total agricultural water demand* minus the *available surface water for agriculture*, divided by the *total agricultural water demand*. We did not take into account groundwater availability for the calculation of *water scarcity ratio* since it is not considered a renewable resource. In fact, there is plenty of groundwater availability at the moment since the shallow aquifer is being recharged due to water excess from irrigation but very often it is illegally pumped, according to public authorities.

The increase of *irrigated land areas* depends on the *change in irrigated land area*, which is a function of the existing *irrigated land areas* and the *potential growth rate of agriculture based on water availability*, which is a function of the *water scarcity ratio.* This doesn't account for groundwater that could be used to decrease the water scarcity because the main driver of the agricultural expansion is indeed the Tagus-Segura water transfer. Groundwater has been historically very limited and its current availability is only due to the high recharge rates by irrigation effluents.

### 3.6.4 Pilot model sector 2 design: Agricultural nutrients balance

Based on the CLD developed by the stakeholders, the most important source of nutrient inputs to the lagoon was the excessive fertilization of the irrigated agricultural areas in the Campo de Cartagena, which caused ground-and surface water pollution coming principally from fertilizers.

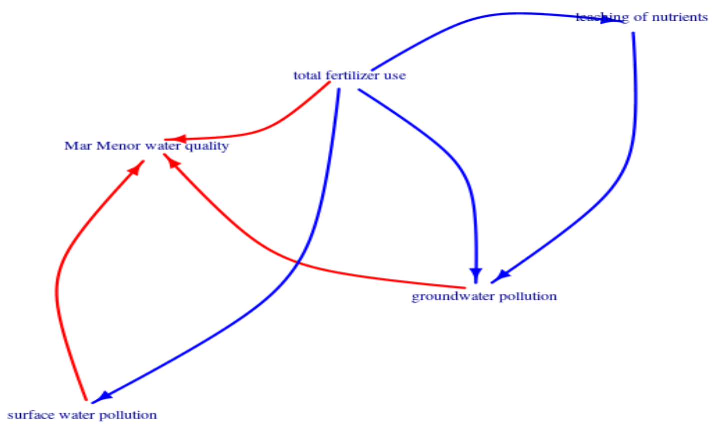


*Figure 98: Excerpt from the CLD related to agricultural nutrients balance. Red and blue arrows represent negative and positive relationships, respectively.*

#### 3.6.4.1 Model scope of Agricultural nutrients balance

This model sector focuses on the quantification of the nutrient's export from irrigated agricultural areas to the Mar Menor lagoon based on the amount of fertilization. It includes some scenarios (variables in green colour) in relation to some potential end-of-pipe solutions, according to the current set of proposed management actions by the regional and national authorities, and supported by some of the stakeholder groups.

#### 3.6.4.2 Quantification of Agricultural nutrients balance

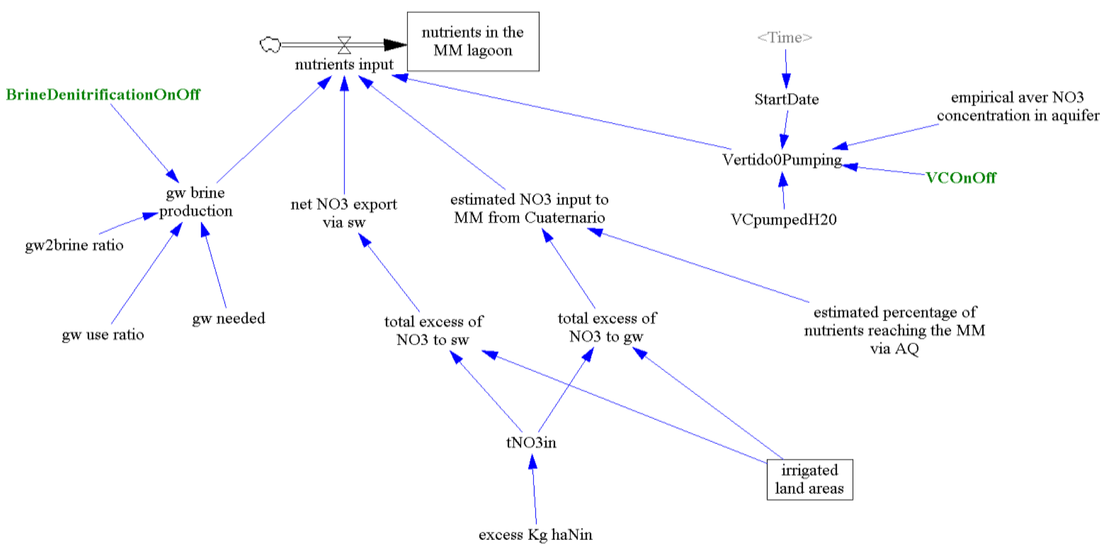


*Figure 99: SD model structure for the agricultural nutrients balance sector. Green colour variables represent main scenarios.*

There are three main sources of agricultural nutrient inputs to the Mar Menor lagoon, i.e. nutrients contained in (1) surface water (sw) runoff (*net NO3 export via sw*), (2) in groundwater (*estimated NO3 input to MM from Cuaternario* aquifer) and (3) in brine wastes (*gw brine production* - resulting from polluted water being pumped from the aquifer and then treated to remove excessive salts and nutrients). This model sector is primarily driven by the excessive use of fertilizers per hectare (*excess Kg haNin*) and by agricultural expansion (*irrigated land areas*). The *excess Kg haNin* refers to Kg/ha of Nitrogen, which is then converted into tons of nitrate per hectare as *tNO3in*. The *total excess of NO3 to gw* and *sw* are calculated based on the percentage from the nitrate that goes to ground- and surface-water, respectively. Since the water and nutrient fluxes in the soil and aquifers are complex processes which would require a different modelling approach, we established an *estimated percentage of nutrients reaching the MM via the aquifer (AQ)* based on literature data, which is multiplied by the *total excess of NO3 to gw* and gives the *estimated NO3 input to MM from the Cuaternario* aquifer. For the surface water nutrients export, another variable is included, the *net NO3 export via sw*, as a function of the *total excess of NO3 to sw* weighted by the effect of sustainable land management practices that could be implemented as a scenario, and is explained in the section corresponding to the model add-on 3.

Since the aquifer is polluted with nutrients, when groundwater is pumped to be used for irrigation, part of it is treated to exclude salts and nutrients, thereby producing brine, which is discarded by farmers. The *gw brine production* variable corresponds to the tons of nitrate produced and exported to the lagoon and is calculated as a function of the *gw needed*, the *gw use ratio* (both explained in the previous section) and the *gw2brine* ratio (the proportion of brine mass in groundwater). The effect of a technology being currently developed that can be used for treating brine wastes by means of pine bark is included in the model as a scenario (*BrineDenitrificationOnOff*) that would avoid the export of these brine wastes to the lagoon.

The Vertido Cero Plan, as explained in the previous section, is based on extracting water from the aquifer in order to reuse the water, once denitrified, and is also expected to decrease the nutrient inputs from the aquifer to the lagoon directly (via groundwater flux) or indirectly (via superficial base flow coming from the aquifer). The *Vertido0Pumping* variable calculates the amount of nutrients that would not reach the Mar Menor once the infrastructure would start working (*StartDate*) based on the total water pumped (*VCpumpedH20*) and the *empirical average NO3 concentration measured in the aquifer*.

The nutrients input to the lagoon is finally computed as the sum of the *estimated NO3 input to MM from Cuaternario*, the *gw brine production* and the *net NO3 export via sw* minus the *Vertido0Pumping*. The nutrients in the MM lagoon are then accumulated and will be related to the degradation of the lagoon, as explained in the section corresponding to model sector 4.

### 3.6.5 Pilot model sector 3 design: Sectorial development and economic profit

As Figure 100, extracted from the CLD, shows, the discussions during the workshops pointed out that most of the economic profit in the study area depended on the development of the agricultural and tourist sectors and partially also on the fisheries and salt pans sector. However, it was also suggested that promoting different economic sectors, including the renewable energy sector, could increase or maintain the total economic profit and help creating new jobs.

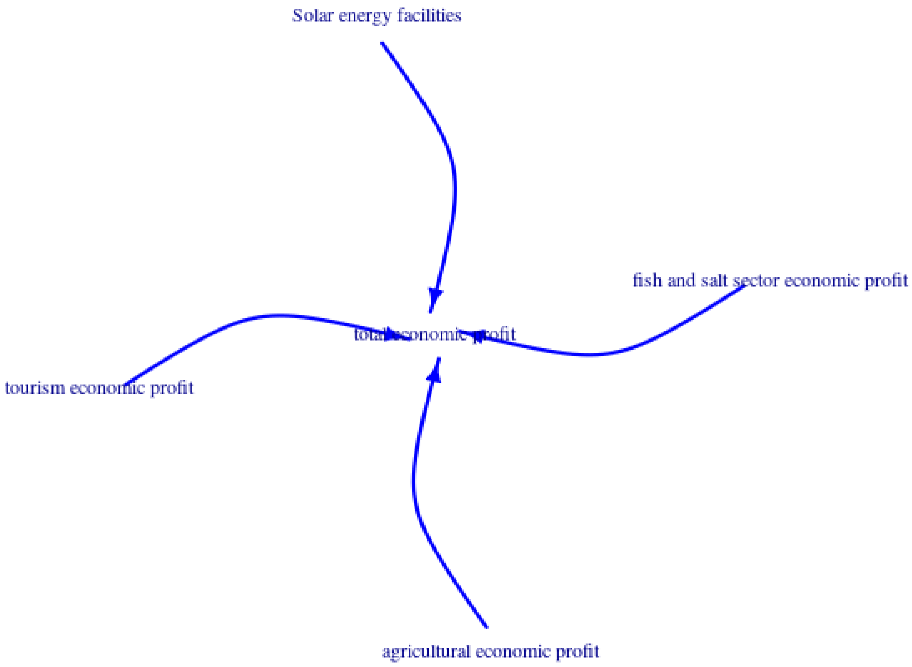


*Figure 100: Excerpt from the CLD related to sectorial development and economic profit. Red and blue arrows represent negative and positive relationships, respectively.*

#### *3.6.5.1 Model scope of Sectorial development and economic profit*

This model sector tries to reproduce and predict the development of the three main sectors mentioned during the workshops, i.e. agriculture, tourism and solar photovoltaic facilities, in the study area. The model includes the development of each sector together with the number of jobs created and its economic profit. The development of the fisheries and saltpan sector in the Mar Menor lagoon is not taken into account because given its small scale it does not contribute significantly to the total economic benefit in the study area but it will be taken into account in a future version of the model within the add-on related to coastal-rural recreation potential. The next subsection presents the development of each sector individually.

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### 3.6.5.2 Quantification of Sectorial development and economic profit

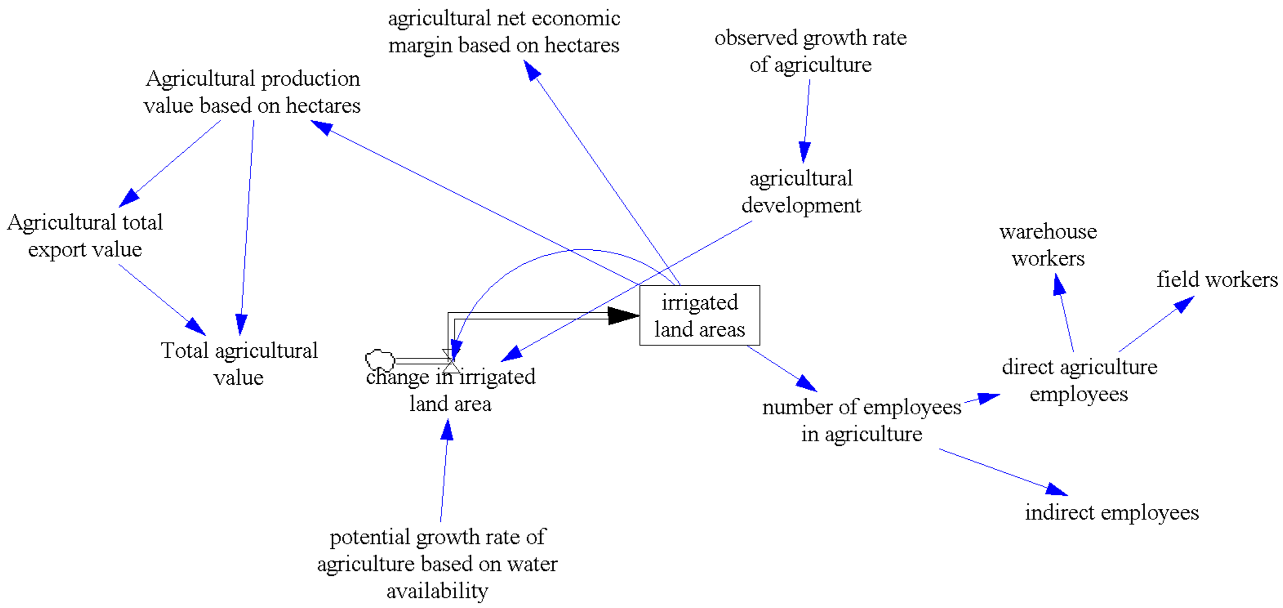



*Figure 101: SD model structure related to agricultural development.*

The total surface area of irrigated land is the main driving factor for economic agricultural development. The *change in irrigated land area* is driven by (1) the *potential growth rate of agriculture based on water availability* (explained in a previous section), (2) the current extent of *irrigated land areas* and (3) the *agricultural development* (percentage), which depends on the historical *observed growth rate of agriculture* plus other variables that will be explained in the section about the model add-on 2. The model imposes a limit of 90,000 hectares to the *irrigated land areas* based on spatial constraints of the geographical area. The *number of employees in agriculture* is based on the extent of *irrigated land areas* and a further characterisation of the job type is included, such as *direct and indirect agriculture employees.* From the direct workers and estimation of the number of *warehouse and field workers* is also calculated. On the other hand, the *agricultural production value and net economic margin based on hectares* are calculated based on the extent of *irrigated land areas*. Then, the *agricultural total export value* is calculated based on the *agricultural production value based on hectares* and the *total agricultural value* is finally computed as the sum of the production and export values.

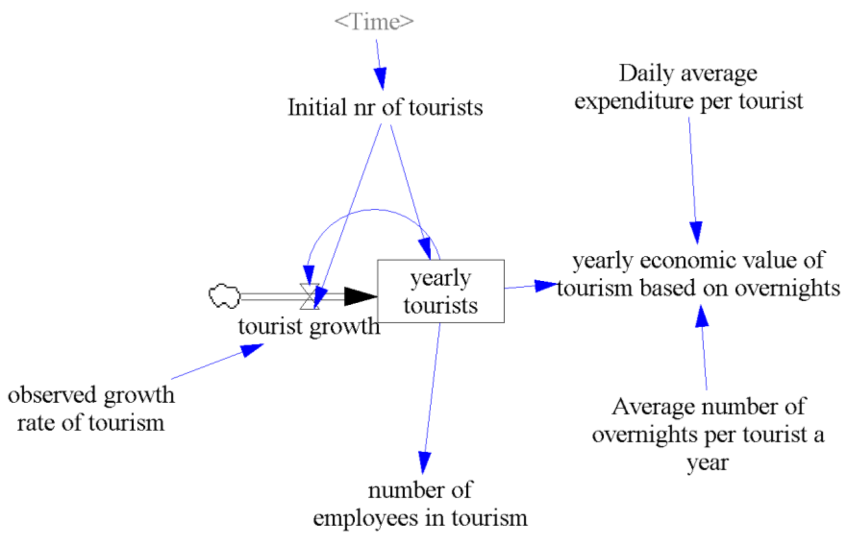



*Figure 102: SD model structure related to tourism development.*

The economic profit of tourism development depends on number of tourists, their per capita expenditure, and the number of jobs created. The number of *yearly tourists* increases as a function of the *tourist growth*, which depends on the historical *observed growth rate of tourism* and the current number of *yearly tourists*. The *number of employees in tourism* is calculated based on the *yearly tourists*. The *yearly economic value of tourism based on overnights* is calculated as a function of the *yearly tourists*, the *average number of overnights per tourist a year* and the *daily average expenditure per tourist*. Thus, the model takes into account the effect of seasonality via the average number of nights, as well as the type of tourist attracted via the average expenditure per tourist.

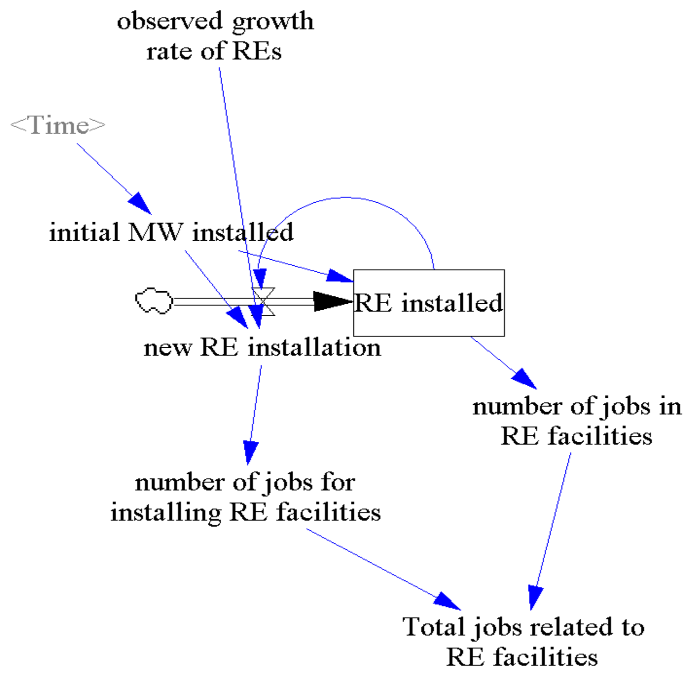



*Figure 103: SD model structure related to renewable energy development.*

The Renewable energy installed (*RE installed*) refers to the total power capacity of solar photovoltaic energy installed measured in Megawatts. *New RE installation* depends on the *RE installed* and the *observed growth rate of RE* (percentage). The *number of jobs for installing RE* facilities depends on the *new RE installation* and the *number of jobs in RE facilities* depends on the *RE installed*. The number of *total jobs related to RE facilities* is then calculated as the sum of both job types.

### 3.6.6 Pilot model sector 4 design: Mar Menor degradation

Figure 104 shows the main drivers of the degradation of the Mar Menor lagoon based on the CLD built upon the stakeholder workshops, being most of them related to the input of fertilizers to the lagoon via surface- or ground-water sources. No specific mechanism was described during the workshops that could explain in detail the ecological processes within the lagoon that led to the collapse that the lagoon started suffering in 2016. However, the scientific knowledge clearly points at eutrophization episodes caused by long term agricultural export of fertilizers as main driver of the environmental degradation.

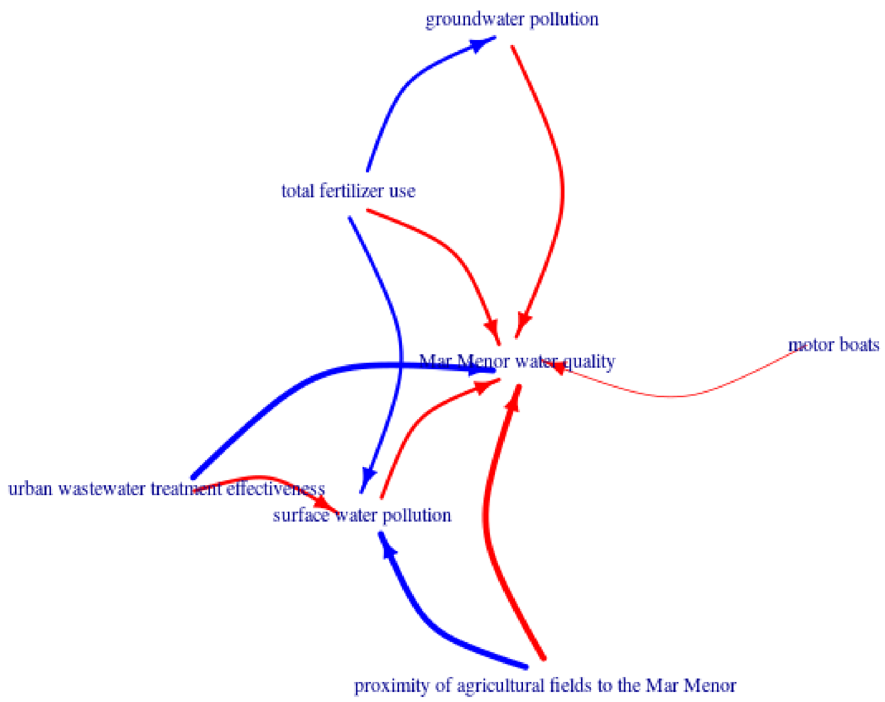



*Figure 104: Excerpt from the CLD related to the Mar Menor degradation. Red and blue arrows represent negative and positive relationships, respectively.*

#### *3.6.6.1 Model scope of Mar Menor degradation*

Based on the CLD and the limited scientific knowledge about the process of ecosystem collapse in the lagoon, this model sector tries to exemplify the degradation of the Mar Menor lagoon linked to the long-term inputs of nutrients observed and modelled in the Agricultural nutrients balance sector.

#### *3.6.6.2 Quantification of Mar Menor degradation*

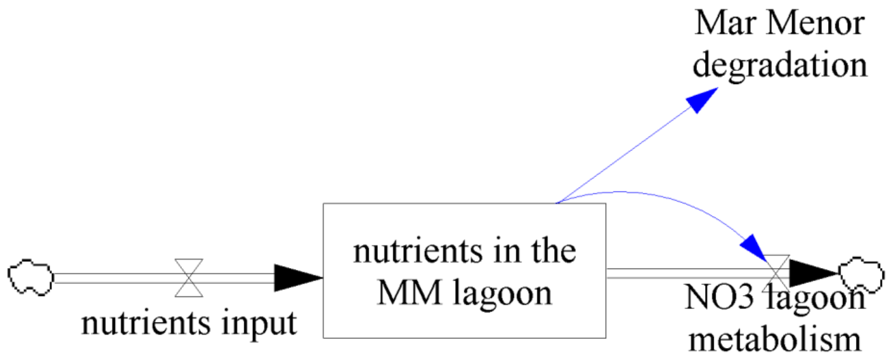



*Figure 105: SD model structure for the Mar Menor degradation sector.*

The *nutrients in the Mar Menor (MM) lagoon* are accumulated over time and are calculated as the difference between the *nutrients input* (explained in the model sector 2) and the *NO3 lagoon metabolism*, which is capable of processing a fraction of the total nutrients accumulated. The *Mar Menor degradation* is then calculated using a response curve calibrated using historical observations of the lagoon ecological status based on Chlorophyll abundance.

### 3.6.7 Pilot model add-on 1 design: Coastal-rural recreation potential

The importance of decreasing tourism seasonality by increasing inland and coastal recreation potential in the study area was pointed out in the workshops and included in the CLD (Figure 106 and Figure 107) as one of the main solutions to promote the local economy and move towards more sustainable business solutions, making the region economicaly less dependent on intensive agriculture. Stakeholders pointed out a strong need to foster development of agrotourism (sustainable agriculture) and ecotourism (educational and sports activities with low environmental impact, such as fishing tourism and diving/snorkeling). To support these ideas, they consider important to promote quality brands (labelling) of local products, as well as short marketing channels (consumption of local products). They also proposed to promote tourism related to nautical activities without motor as the main priority: e.g. sailing, especially sailing adapted for disabled people, and rowing, taking advantage of the exclusive conditions for practicing sports throughout the year. They also highlighted the need to exemplify good agricultural practices in demonstration farms, fairs and eco-markets, as well as to promote gastronomic tourism based on local agricultural products. This combination of initiatives would improve the quality of the services sector and increase environmental awareness while promoting a transition towards more sustainable tourism and agriculture sectors because they would both benefit from a good environmental status.

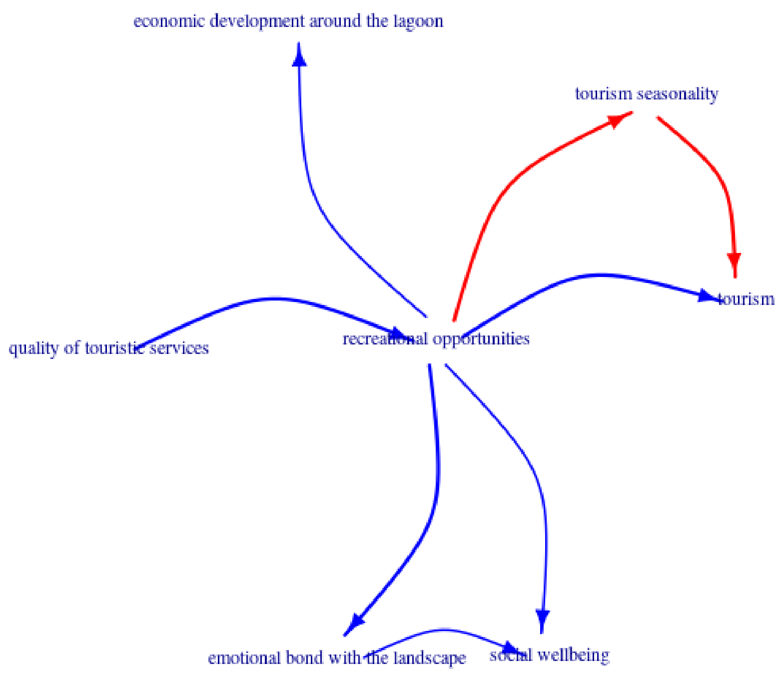



*Figure 106: Excerpt from the CLD related to coastal-rural recreation potential outgoing variables. Red and blue arrows represent negative and positive relationships, respectively.*

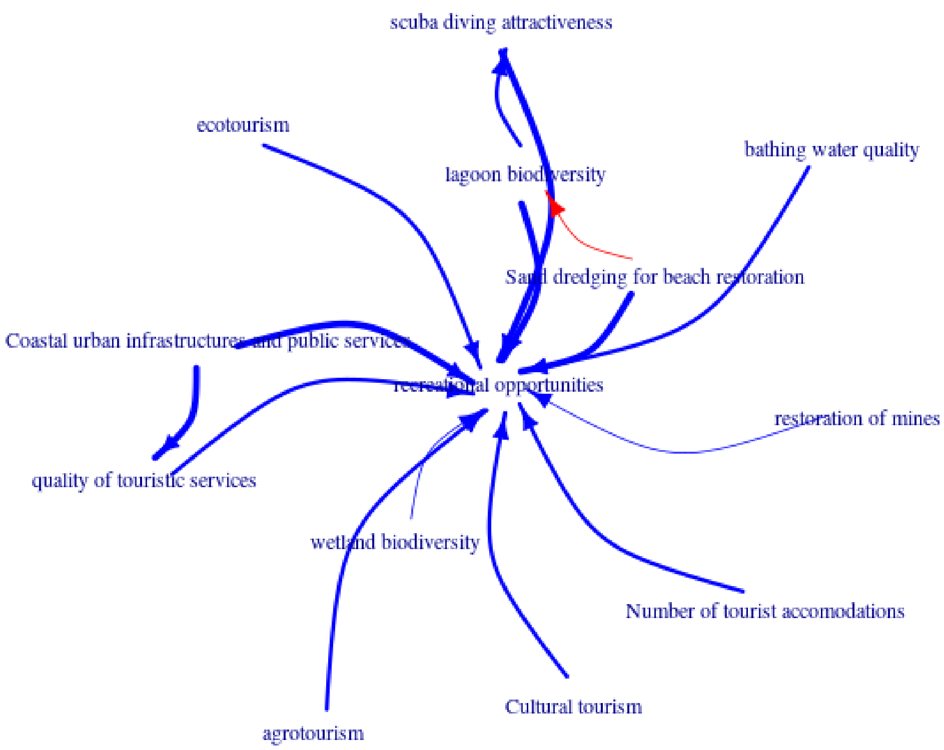



*Figure 107: Excerpt from the CLD related to coastal-rural recreation potential incoming variables. Red and blue arrows represent negative and positive relationships, respectively.*

#### 3.6.7.1 Model scope of Coastal-rural recreation potential

In this model add-on we assess the influence of the degradation of the Mar Menor in the coastal recreation potential, as well as the effect of increasing the rural and coastal recreation potential on the tourist growth.

#### 3.6.7.2 Quantification of Coastal-rural recreation potential

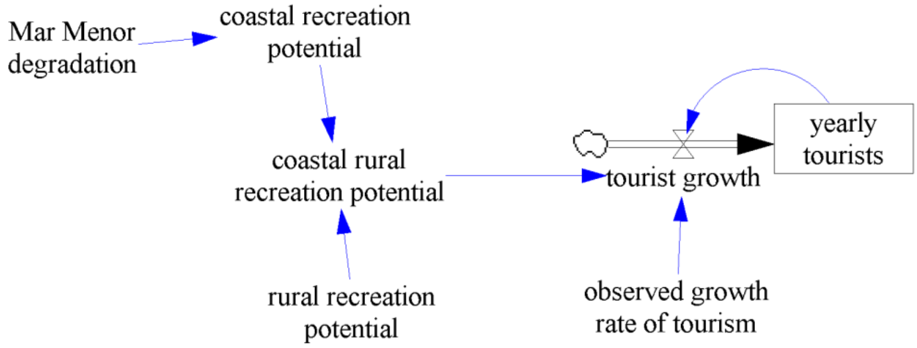



*Figure 108: SD model structure for the coastal-rural recreation potential add-on.*

The *tourist growth* variable, primarily depending on the *observed growth of tourism*, as explained in model section 3, also accounts for the *coastal rural recreation potential*, which is the sum of the *coastal* and *rural recreation potential*. The increase of the coastal and rural recreation potential will be estimated in future versions of the model based on different initiatives that were mentioned during the workshops, such as agrotourism. Besides, the Mar Menor degradation already affects coastal recreation potential.

### 3.6.8 Pilot model add-on 2 design: Social awareness and governance

During the workshops environmental education, social awareness and participatory governance were pointed out to be crucial in order to overcome the current ecological crisis while promoting a sustainable economic development. Figure 109 and Figure 110 show exmaples from the CLD in which those variables play an important role. More especifically, stakeholders considered crucial to increase the public awareness of the environmental and economic value of the lagoon through the promotion of participatory workshops on environmental topics, including environmental values of the territory, to explain the ecosystem services of the lagoon in the entire Murcia Region, Mar Menor and Campo de Cartagena catchment, since many tourists from the Mar Menor belong to the Region of Murcia. To further support implementation and a more effective management they proposed to create a specific coordinating body for the Mar Menor and its catchment area, formed mainly by public administrations, but closely collaborating with other stakeholders through participatory governance. They suggested to promote planning in the medium and long term by public administrations. These initiatives will favor that the population remains in the territory and will promote the regeneration of the Mar Menor ecosystem by means of providing resources and financing studies to improve the water quality levels, as well as to avoid contamination by runoff from the catchment.

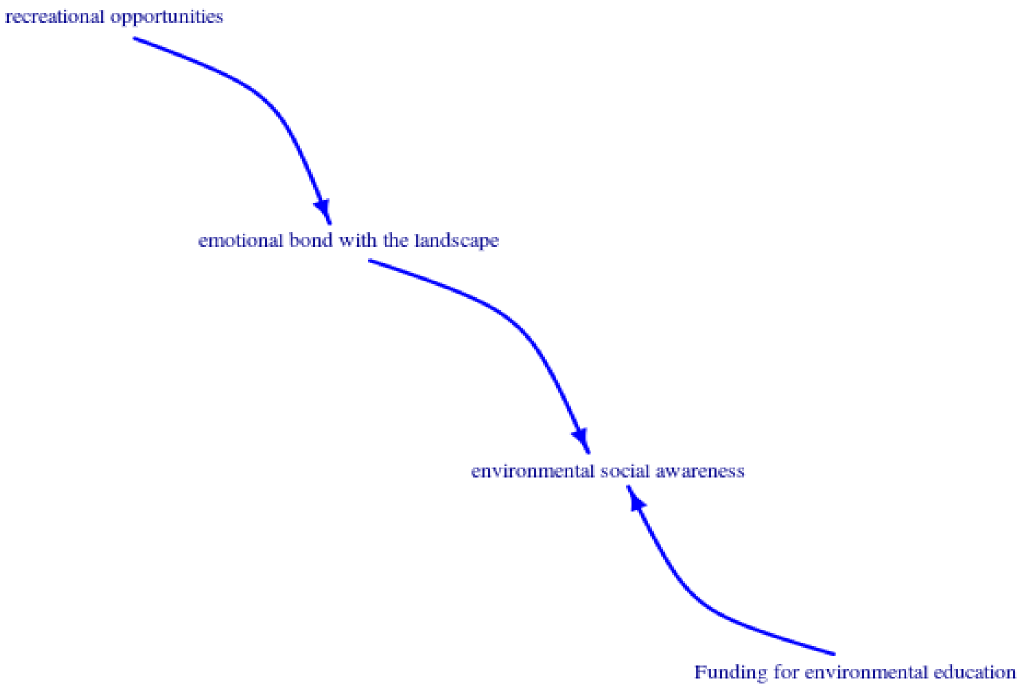



*Figure 109: Excerpt from the CLD related to the promotion of social awareness and governance. Red and blue arrows represent negative and positive relationships, respectively.*

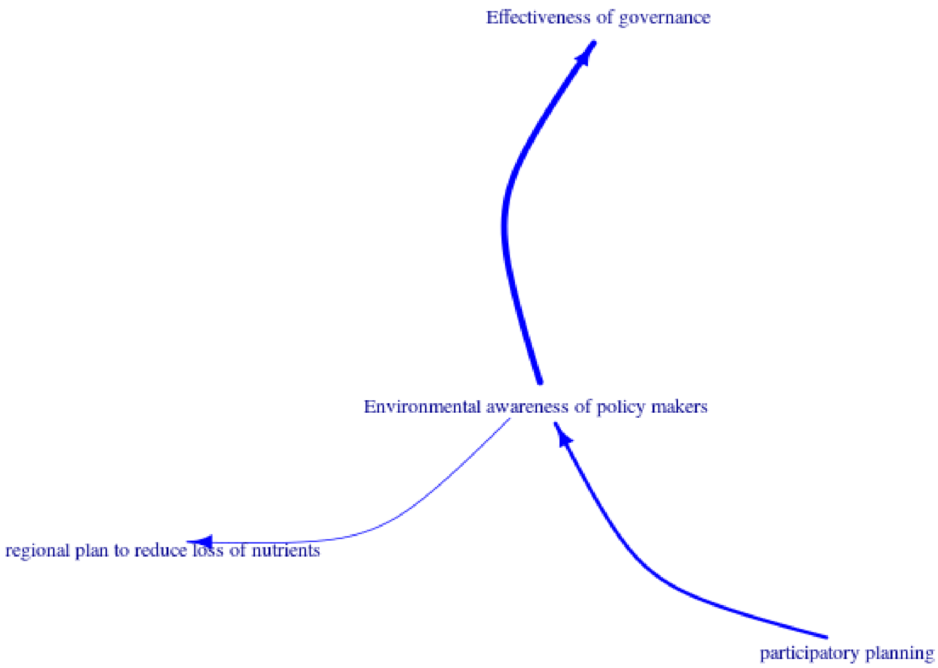


*Figure 110: Excerpt from the CLD related to the effects of social awareness and governance. Red and blue arrows represent negative and positive relationships, respectively.*

#### 3.6.8.1 Model scope Social awareness and governance

Given the importance that stakeholders attributed to social awareness and environmental education, this model add-on implements two mechanisms that represent social and governance feedbacks in relation to the regulation and development of the different sectors that take place in the study area, and particularly of the agricultural sector.

#### 3.6.8.2 Quantification Social awareness and governance

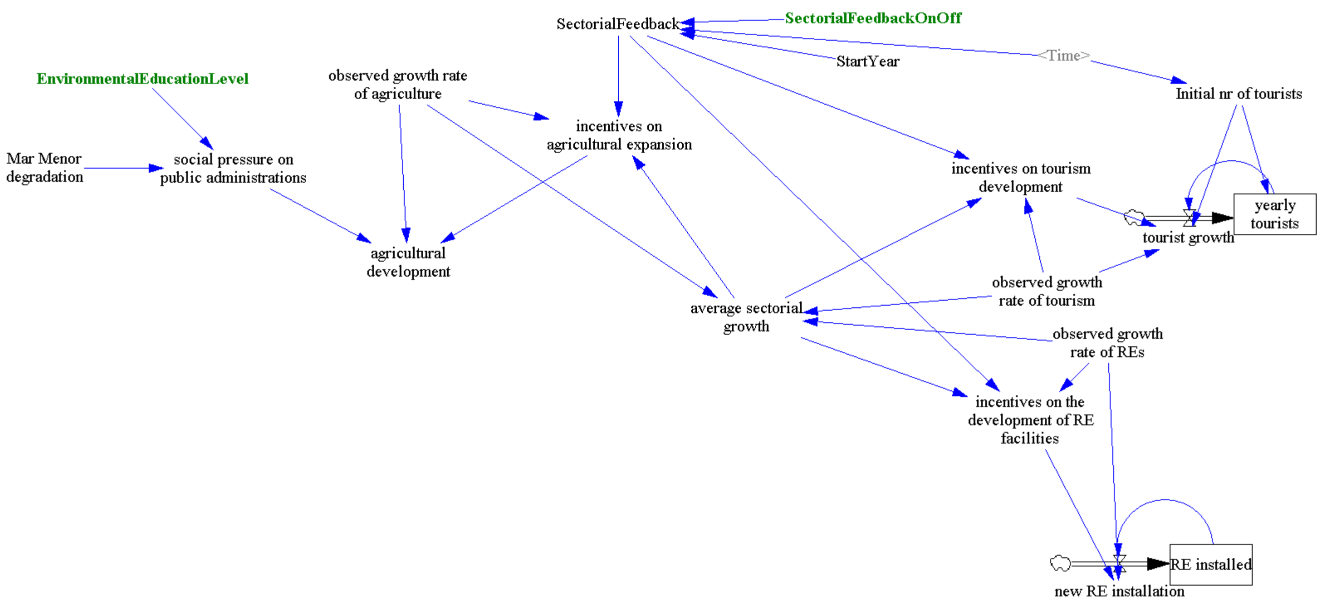



*Figure 111: SD model structure for the social awareness and governance add-on. Green colour variables represent main scenarios.*

The *agricultural development* variable, primarily a function of the *observed growth rate of agriculture*, as explained in model sector 3, is also made dependent on the *social pressure on public administrations*, which is calculated using a response curve function based on the *Mar Menor degradation* weighted by the environmental education level scenario (*EnvironmentalEducationLevel; from 0 to 1*). On the other hand, a governance feedback scenario is included in relation to the regulation and development of the different sectors that take place in the study area (*SectorialFeedback*), aiming for sustainable and equivalent development of each sector. The feedback mechanism consists of applying *incentives on agricultural/tourism/Res development* as a function of the *average sectorial growth*. This latter variable is calculated taking the average of all the sectorial observed growth values. The growth of each sector is then promoted or slowed down based on the difference between the observed growth value of the sector and the average sectorial growth, resulting in positive or negative incentives which are added to the observed growth value of the sector.

### 3.6.9 Pilot model add-on 3 design: Sustainable land management practices

Sustainable land management (SLM) practices in agriculture, such as a decrease in the use of fertilizers, or their retention through buffer strips and establishment of a green covers, can have several beneficial effects on agricultural production and the environment, as can be seen in Figure 112 based on the CLD.

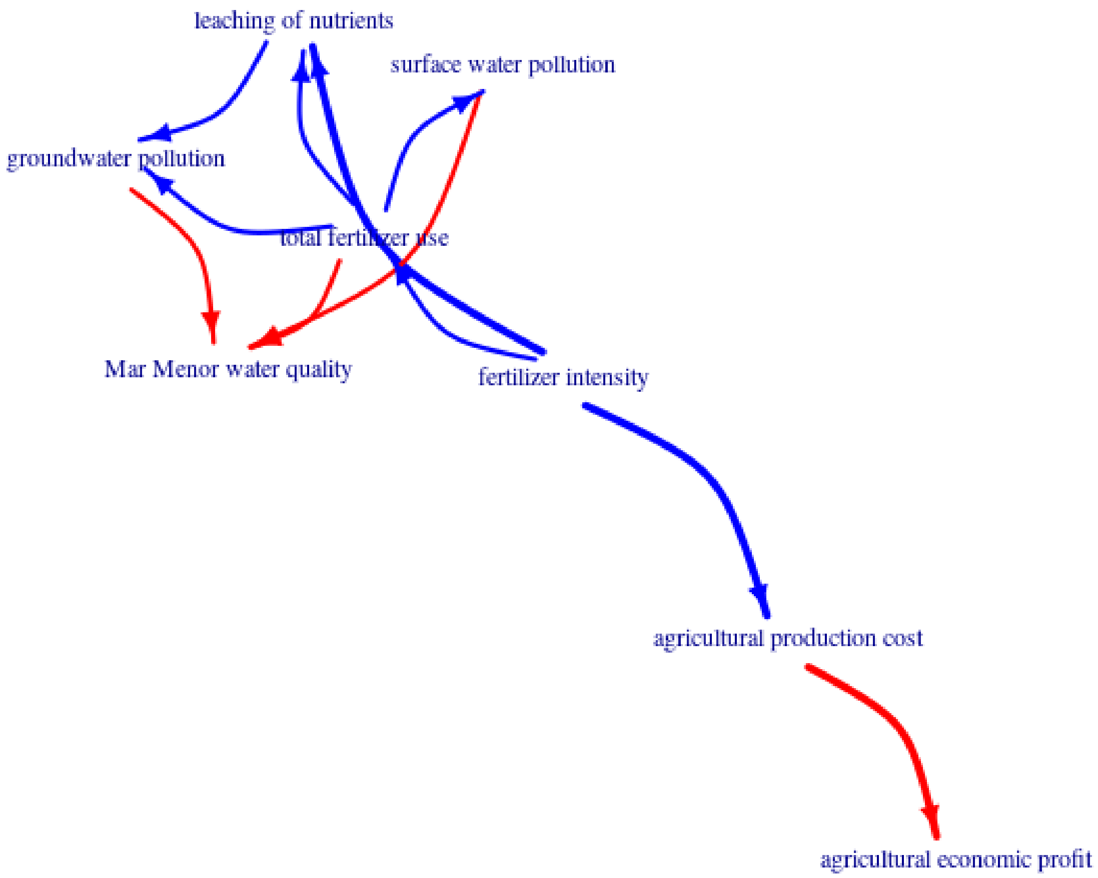



*Figure 112: Excerpt from the CLD related to sustainable land management practices. Red and blue arrows represent negative and positive relationships, respectively.*

#### *3.6.9.1 Model scope Sustainable land management practices*

In this model add-on, we have started quantification of the benefits of implementing two SLM practices in our case study, such as the decrease in the application of fertilizers and the implementation of vegetation buffers around agricultural fields.

#### 3.6.9.2 Quantification Sustainable land management practices

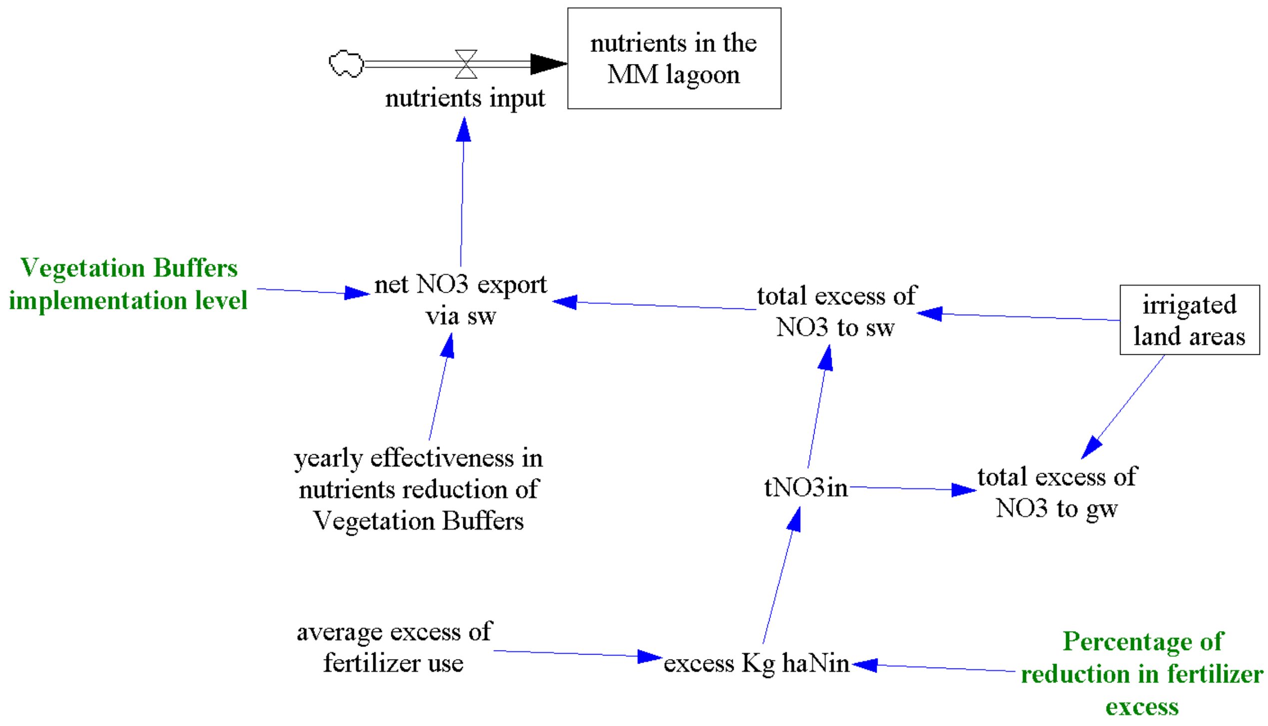



*Figure 113: SD model structure for the sustainable land management practices add-on. Green colour variables represent main scenarios.*

The *excess Kg haNin*, explained as part of model sector 2, is influenced by the *average excess of fertilizer use* (Kg/ha of Nitrogen input) and weighted by a scenario based on the p*ercentage of reduction in fertilizer excess*. This scenario influences the input of nutrients via surface- and groundwater. On the other hand, in relation to surface water nutrients input, the implementation of vegetation buffers around agricultural areas is also included as a scenario (*Vegetation Buffers implementation level*; from 0 to 1) which affects the *net NO3 export via sw*, together with the *total excess of NO3 to sw* and the *yearly effectiveness in nutrients reduction of Vegetation Buffers* (percentage).

### 3.6.10 Overview of the stock-flow models and land sea interactions

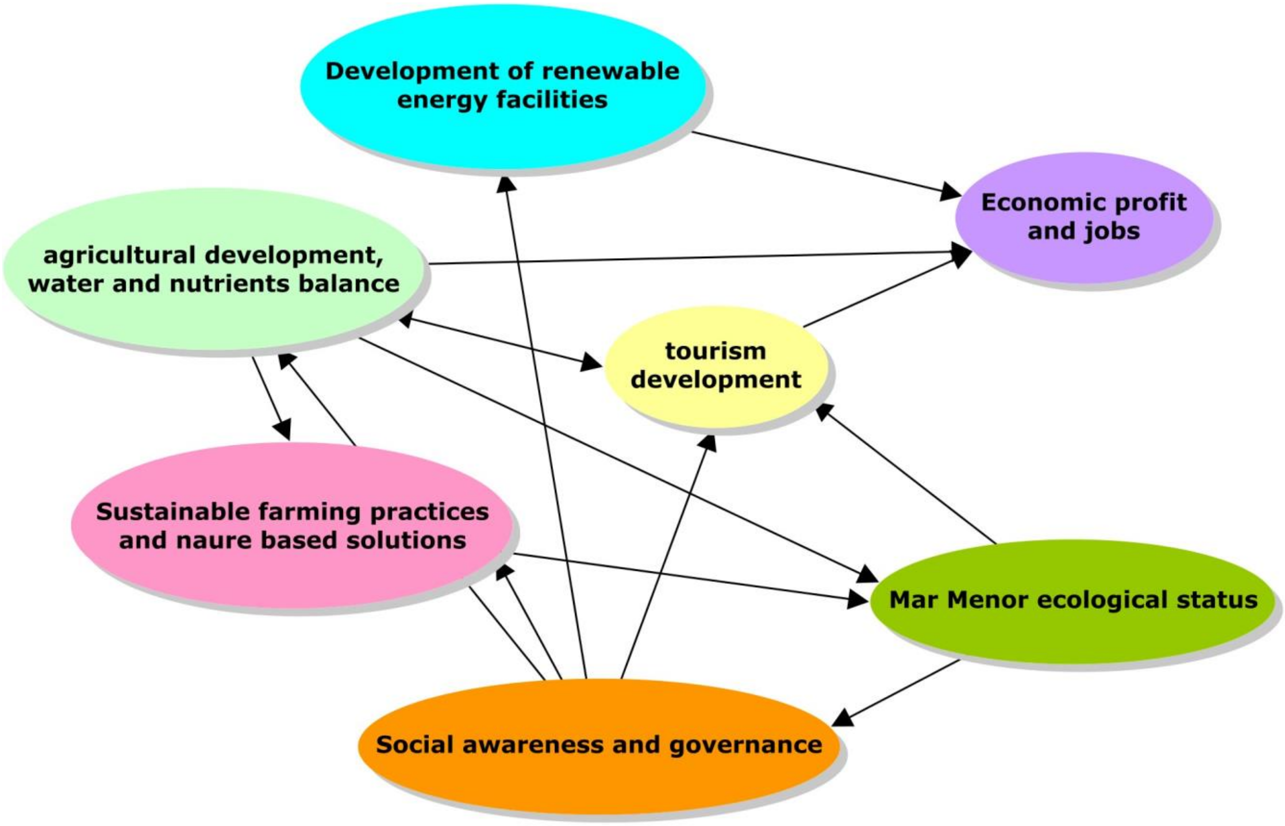



*Figure 114: Overview of the sectors and add-ons of the MAL6 pilot system dynamic model.*

Figure 114 shows an overview of the pilot system dynamic model presented here, highlighting the relationships among the different topics modelled. All three economic sectors (agriculture, tourism, photovoltaic renewable energy) contribute to the total economic profit and jobs in the study area. The Mar Menor ecological status is influenced by the agricultural development via water and nutrients input and the implementation of SLM practices and nature based solutions. On the other hand, the ecological status of the lagoon affects tourism development and social awareness and governance, which in turn might lead to the adoption of SLM practices and the implementation of NBS, and regulate the development of the different economic sectors. Besides, there is a potential synergy between the agricultural and the tourist sectors via promoting agrotourism activities. Figure 115 shows the main feedback loops contained in the model structure. The Mar Menor degradation, mainly caused by agricultural nutrient inputs and indirectly affecting tourist growth via recreation potential, affects social pressure on public administrations, which in turn negatively affects agricultural development. Besides, the expansion of irrigated land areas increases water demand and water scarcity, which in turn decreases the potential growth of agriculture based on water availability. Furthermore, the increase in agricultural water demand also increases the groundwater needed, thereby producing brine wastes and more nutrients inputs to the lagoon. The social pressure on public administrations and the implications for agricultural and tourism growth potential are central in the effectiveness of this feedback loop.

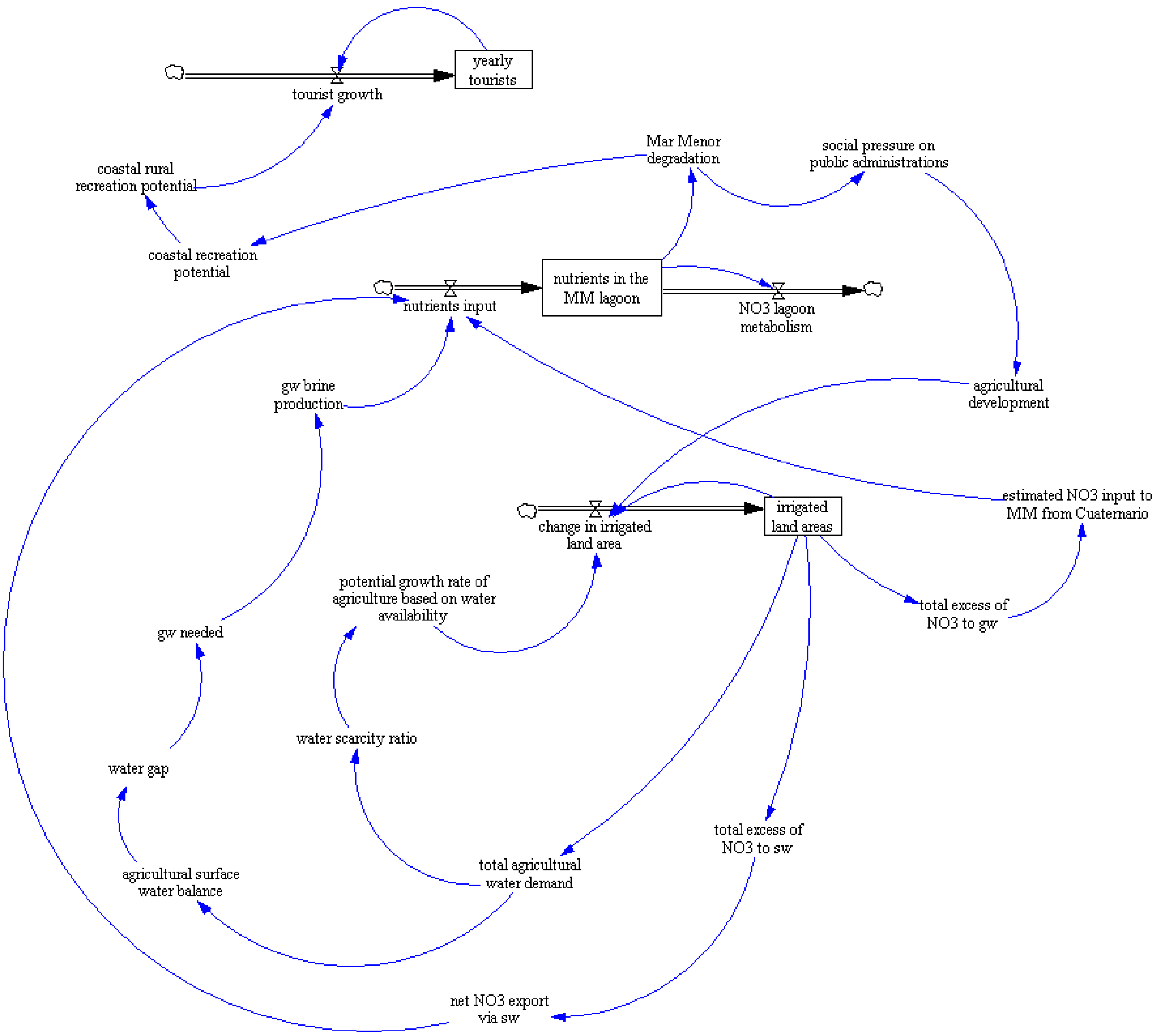



*Figure 115: Main feedback loops of the MAL6 pilot system dynamic model.*

The ultimate goal of the system dynamic model under development is to support and guide the transition to a future vision developed by the stakeholders in which the Campo de Cartagena and Mar Menor lagoon are internationally recognized as well developed coastal and rural ecotourism destinations, in which there is also room for sustainable agriculture, and synergistic development between agriculture and tourism. The tourism and agriculture sectors will be interdependent and collaborating for sustainable development. The strong presence of sustainable tourism activities creates the incentives for developing and preserving healthy rural areas, sea and coasts, combined with good quality infrastructures and level of general well-being for people living in the area. All sectors will work together following a problem-based approach and promoting economic benefit transfer from coastal to rural areas and vice versa. New regulations from local to national level will be developed, incorporating and considering the environmental, social and economic aspects of sustainable development. All economic sectors will have internalized environmental costs and benefits in their business models. The agricultural sector will be aware of its role and impact on the Mar Menor lagoon driven by a change in attitude from local and international consumers, who will consciously buy vegetables and fruits produced by means of sustainable land management practices. Thus, agriculture in the area will make a transition to high quality products with a high added value, applying the latest technology for water and nutrient efficiency and concepts of sustainable intensification. Production will be more oriented to local markets and tourism and solar energy will become an attractive alternative for agricultural land use. There will be an expansion of tourism activities linked to agriculture (agrotourism) and to alternative activities in rural and coastal areas that attract international (water and land) sport events taking advantage of the soft winters. There will be a coordinating body for the Mar Menor and its catchment area formed by public administrations and representatives from all socio-economic sectors that will co-manage the area with strong participation from all stakeholders. All sectors will follow a common regulation to minimize and mitigate nutrient and pollutant emissions as a long-term goal. This will also supported by building new green infrastructures based on nature-based solutions and the wide scale adoption of sustainable land management practices in the agriculture sector that help protecting the lagoon and villages from flooding and contamination.

### 3.6.11 Problems that can be addressed with the SD models

The list of scenarios below that can be evaluated with the SD model corresponds to the potential solutions coming from the stakeholder workshops.

1. Water pumping from the aquifer to extract pollutants and provide additional irrigation water (Vertido Cero Plan).
2. Limitation in the number of groundwater wells.
3. Implementation of nature based solutions related to agricultural areas, such as vegetation buffers.
4. Promotion of environmental education among local populations.
5. Government control on sectorial growth (participatory governance).
6. Enforcement of decrease in the application of fertilizers (also linked to EU Green Deal biodiversity and farm-to-fork strategy).
7. Implementation of brine denitrification technologies.
8. Effect of the implementation of solar photovoltaic facilities in job availability.
9. Effect on water availability of a decrease in water transfer from the Tagus-Segura transfer driven by climate change (or by stopping the water transfer).
10. Effect of a change in agricultural water demand per hectare based on higher potential evapotranspiration due to climate change or the use of low water consumption crops.

### 3.6.12 Main model variables

*Table 10: main variables in the model (Role: I: input, O: indicator); SD: S: stock, F: flow, A: auxiliary)*

| Topic | Name | Unit | Role | SD model meaning | Definition |
|---|---|---|---|---|---|
| **Agricultural water balance** | ActualNrWorkingWells | Count | | A | Number of active wells |
| **Agricultural water balance** | agricultural surface water balance | Hm3 | | A | It corresponds to the available surface water for agriculture (plus the VC water pumped) minus the total agricultural water demand |
| **Agricultural water balance** | agricultural water demand per hectare | Hm3/Ha*year | I | A | Average agricultural water demand per hectare and per year |
| **Agricultural water balance** | AllowedNrWells | Count | I | A | This variable represents a scenario in which the number of wells is limited by legislation |
| **Agricultural water balance** | annual groundwater pumping by well | hm3/well | I | A | Average annual groundwater pumping by well |
| **Agricultural water balance** | ATS opened | Dimensionless | | A | A switcher that opens the Tagus-Segura |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | water transfer in 1979 |
| **Agricultural water balance** | available surface water for agriculture | Hm3/year | | A | The sum of all surface water sources |
| **Agricultural water balance** | Available water from Tagus river | Hm3/year | | A | The yearly average amount of water that has been transferred or is predicted to be transferred based on CC scenarios. |
| **Agricultural water balance** | available water from the TS water transfer | Hm3/year | | A | The water diverted to the Campo de Cartagena from the Tagus-Segura aqueduct |
| **Agricultural water balance** | average TS water transfer | Hm3/year | | A | The water actually transferred as long as the aqueduct opened |
| **Agricultural water balance** | CRCC share of ATS | percentage | I | A | The percentage of water that is assigned to the Comunidad de Regantes del Campo de Cartagena |
| **Agricultural water balance** | gw needed | Hm3/year | | A | Total amount of groundwater needed to meet the |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | agricultural water demand |
| **Agricultural water balance** | gw use ratio | Percentage | | A | The fraction of groundwater needed that is actually pumped based on the number of working wells |
| **Agricultural water balance** | NeededNrWells | Count | | A | The number of wells needed in order to pump all the groundwater demanded |
| **Agricultural water balance** | other post TS water sources | Hm3/year | I | A | Additional sources of surface water available for the Campo de Cartagena |
| **Agricultural water balance** | sea water desalination | Hm3/year | I | A | Sea water desalinated that serves as an input for the agricultural water demand |
| **Agricultural water balance** | total agricultural water demand | Hm3/year | | A | Total agricultural water demand |
| **Agricultural water balance** | total available water for agriculture | Hm3/year | O | A | The sum of the available surface water for agriculture and the groundwater pumped |
| **Agricultur** | treated gw produced | Hm3/year | | A | Total amount |

| | | | | | |
|---|---|---|---|---|---|
| **al water balance** | | | | | of groundwater extracted from the aquifer |
| **Agricultural water balance** | urban wastewater treatment plant effluents | Hm3 | I | A | urban wastewater treatment plant effluents that serve as an input for the agricultural water demand |
| **Agricultural water balance** | VCpumpedH20 | Hm3/year | I | A | Water extracted from the aquifer by the Vertido Cero Plan |
| **Agricultural water balance** | water gap | Hm3/year | | A | The agricultural water needed not met by the surface water sources |
| **Agricultural water balance** | water scarcity ratio | Percentage | | A | The fraction of the total agricultural water demand that is not met by the available surface water for agriculture |
| **Sectorial develop-ment and economic profit** | agricultural development | Percentage | | A | Final agricultural development |
| **Sectorial develop-ment and economic profit** | agricultural net economic margin based on hectares | EUR | O | A | Total net profit of agricultural producers |

| | | | | | |
|---|---|---|---|---|---|
| **Sectorial develop-ment and economic profit** | Agricultural production value based on hectares | EUR | | A | Total agricultural production value |
| **Sectorial develop-ment and economic profit** | Agricultural total export value | EUR | | A | Total agricultural export value |
| **Sectorial develop-ment and economic profit** | Average number of overnights per tourist a year | Number of overnights/tourist*year | I | A | Average number of overnights per tourist a year |
| **Sectorial develop-ment and economic profit** | change in irrigated land area | Ha/year | | F | Yearly change in irrigated land area |
| **Sectorial develop-ment and economic profit** | Daily average expenditure per tourist | EUR/person/day | I | A | Daily average expenditure per tourist |
| **Sectorial develop-ment and economic profit** | direct agriculture employees | Count | | A | Total number of direct agriculture employees |
| **Sectorial develop-ment and economic profit** | field workers | Count | O | A | Total number of field workers |
| **Sectorial develop-ment and economic** | indirect employees | Count | O | A | Total number of indirect agriculture employees |

| | | | | | |
|---|---|---|---|---|---|
| **profit** | | | | | |
| **Sectorial develop-ment and economic profit** | initial MW installed | Mw | | A | Initial amount of renewable energy power installed |
| **Sectorial develop-ment and economic profit** | Initial nr of tourists | Count | I | A | Initial number of tourists |
| **Sectorial develop-ment and economic profit** | irrigated land areas | Ha | | S | Extent of irrigated agricultural areas |
| **Sectorial develop-ment and economic profit** | new RE installation | Mw | | F | Change in renewable energy facilities power installed |
| **Sectorial develop-ment and economic profit** | number of employees in agriculture | Count | | A | Total number of employees in agriculture |
| **Sectorial develop-ment and economic profit** | number of employees in tourism | Count | O | A | Total number of employees in tourism |
| **Sectorial develop-ment and economic profit** | number of jobs for installing RE facilities | Count | | A | Total number of employees for the installation of photovoltaic renewable energy facilities |
| **Sectorial** | number of jobs in RE | Count | | A | Total number |

| | | | | | |
|---|---|---|---|---|---|
| **develop-ment and economic profit** | facilities | | | | of employees for the maintenance of photovoltaic renewable energy facilities |
| **Sectorial develop-ment and economic profit** | observed growth rate of agriculture | percentage | I | A | Historical rate of agricultural growth rate |
| **Sectorial develop-ment and economic profit** | observed growth rate of REs | percentage | I | A | Historical rate of renewable energy power growth rate |
| **Sectorial develop-ment and economic profit** | observed growth rate of tourism | percentage | I | A | Historical rate of tourism growth rate |
| **Sectorial develop-ment and economic profit** | potential growth rate of agriculture based on water availability | percentage | | A | The fraction of the total agricultural water demand that is met by the available surface water for agriculture |
| **Sectorial develop-ment and economic profit** | RE installed | Mw | | S | Total power of photovoltaic energy installed |
| **Sectorial develop-ment and economic profit** | Total agricultural value | EUR | | A | The sum of the agricultural production value and the agricultural |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | total export value |
| **Sectorial develop-ment and economic profit** | Total jobs related to RE facilities | Count | O | A | Sum of the number of jobs for installing and maintenance of photovoltaic energy facilities |
| **Sectorial develop-ment and economic profit** | tourist growth | Count/year | | F | Yearly Change in tourists |
| **Sectorial develop-ment and economic profit** | warehouse workers | Count | O | A | Number of warehouse agricultural employees |
| **Sectorial develop-ment and economic profit** | yearly economic value of tourism based on overnights | EUR | O | A | Yearly economic value of tourism |
| **Sectorial develop-ment and economic profit** | yearly tourists | Count | | S | Total number of yearly tourists |
| **Mar Menor degra-dation** | Mar Menor degradation | fraction | | A | Degradation status of the Mar Menor lagoon |
| **Mar Menor degra-dation** | NO3 lagoon metabolism | Tons/year | | F | Amount of nutrient being processed by the Mar Menor lagoon ecosystem |

| | | | | | |
|---|---|---|---|---|---|
| **Mar Menor degra-dation** | nutrients in the MM lagoon | Tons | | S | Total amount of nutrients in the Mar Menor lagoon |
| **Coastal-rural recreation potential** | coastal recreation potential | dimensionless | | A | Relative coastal recreation potential value |
| **Coastal-rural recreation potential** | coastal rural recreation potential | dimensionless | | A | Sum of rural and coastal relative recreation values |
| **Coastal-rural recreation potential** | rural recreation potential | percentage | I | A | Relative rural recreation potential value |
| **Social awareness and governance** | average sectorial growth | percentage | | | Average sectorial growth |
| **Social awareness and governance** | EnvironmentalEducationLevel | dimensionless ranking | I | A | Environmental education level of the local populations |
| **Social awareness and governance** | incentives on agricultural expansion | Percentage | | A | Positive or negative incentives by public administrations in relation to the development of the agricultural sector |
| **Social** | incentives on the | Percentage | | A | Positive or |

| | | | | | |
|---|---|---|---|---|---|
| **awareness and governance** | development of RE facilities | | | | negative incentives by public administrations in relation to the development of the photovoltaic renewable energy sector |
| **Social awareness and governance** | incentives on tourism development | Percentage | | A | Positive or negative incentives by public administrations in relation to the development of the tourism sector |
| **Social awareness and governance** | SectorialFeedback | Dimensionless | | A | Binary variable as a switch to (de)activate the sectorial feedback scenario in a specific year |
| **Social awareness and governance** | SectorialFeedbackOnOff | Dimensionless | I | A | Binary variable as a switch to (de)activate the sectorial feedback scenario |
| **Social awareness and governance** | social pressure on public administrations | Percentage | | A | Relative pressure exerted by an environmentally-aware society |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | on the public administration |
| **Sustainable land manage-ment practices** | average excess of fertilizer use | Kg N/ha*year | I | A | Average excess of Nitrogen (fertilizer) use |
| **Sustainable land manage-ment practices** | net NO3 export via sw | Tons/year | | A | Final amount of nutrient inputs reaching the Mar Menor via surface water once vegetation buffers have been implemented |
| **Sustainable land manage-ment practices** | Percentage of reduction in fertilizer excess | percentage | I | A | Scenario of percentage of reduction in fertilizer excess |
| **Sustainable land manage-ment practices** | Vegetation Buffers implementation level | percentage | I | A | Percentage of irrigated agricultural areas which have implemented vegetation buffers |
| **Sustainable land manage-ment practices** | yearly effectiveness in nutrients reduction of Vegetation Buffers | percentage | I | A | Average percentage of yearly nutrients reduction of vegetation buffers |
| **Agricultural nutrients** | BrineDenitrificationOnOff | Dimensionless | I | A | Binary variable acting as a switch to |

| | | | | | |
|---|---|---|---|---|---|
| **balance** | | | | | (de)activate the brine denitrification scenario |
| **Agricultural nutrients balance** | empirical aver NO3 concentration in aquifer | Ton/Hm3 | I | A | Empirically measured average of NO3 concentration in the Cuaternario aquifer |
| **Agricultural nutrients balance** | estimated NO3 input to MM from Cuaternario | Tons/year | | A | Final amount of nutrient inputs to the Mar Menor via the Cuaternario aquifer |
| **Agricultural nutrients balance** | estimated percentage of nutrients reaching the MM via AQ | Percentage | I | A | Estimated percentage of nutrients reaching the Mar Menor via the Cuaternario aquifer |
| **Agricultural nutrients balance** | excess Kg haNin | Kg/Ha*year | | A | Nitrogen leached in agricultural fields |
| **Agricultural nutrients balance** | gw brine production | Tons/year | | A | Total amount of nutrients from brine exported to the Mar Menor lagoon |
| **Agricultural nutrients balance** | gw2brine ratio | percentage | I | A | Percentage of usable water contained in the groundwater |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | pumped from the aquifer |
| **Agricultural nutrients balance** | nutrients input | Tons/year | | F | Total nutrient inputs to the Mar Menor lagoon |
| **Agricultural nutrients balance** | tNO3in | Tons/Ha*year | | A | Nitrate leached in agricultural fields |
| **Agricultural nutrients balance** | total excess of NO3 to gw | Tons/year | | A | Total amount of nutrients leached to groundwater |
| **Agricultural nutrients balance** | total excess of NO3 to sw | Tons/year | | A | Total amount of nutrients leached to surface water |
| **Agricultural nutrients balance** | VCOnOff | Dimensionless | I | A | Binary variable to switch on or off the Vertido Cero scenario |
| **Agricultural nutrients balance** | Vertido0Pumping | Tons/year | | A | Tons of nutrients extracted from the aquifer by the Vertido Cero water pumping |

### 3.6.13 Data sources


Alcolea, A., Contreras, S., Hunink, J.E., García-Aróstegui, J.L., Jiménez-Martínez, J., 2019. Hydrogeological modelling for the watershed management of the Mar Menor coastal lagoon (Spain). Sci. Total Environ. 663, 901–914. doi:10.1016/j.scitotenv.2019.01.375

Caballero Pedraza, A., Romero Díaz, A., Espinosa Soto, I., 2015. Cambios paisajísticos y efectos medioambientales debidos a la agricultura intensiva en la Comarca de Campo de Cartagena-Mar Menor (Murcia). Estud. geogr. 76, 473–498. doi:10.3989/estgeogr.201517

Carreño, M.F., Palazon, J.A., Martínez-López, J., 2015. 1988-2009 time-series of land-use/land-cover maps for the Mar Menor / Campo de Cartagena watershed by means of supervised classification of Landsat images.

Conesa, H.M., Jiménez-Cárceles, F.J., 2007. The Mar Menor lagoon (SE Spain): A singular natural ecosystem threatened by human activities. Mar. Pollut. Bull. 54, 839–849. doi:10.1016/j.marpolbul.2007.05.007

Fernández, J.M., Selma, M.A.E., 2004. The dynamics of water scarcity on irrigated landscapes: Mazarrón and Aguilas in south-eastern Spain. Syst. Dyn. Rev. 20, 117–137. doi:10.1002/sdr.290

Fernández, J.M., Selma, M.A.E., Aymerich, F.R., Sáez, M.T.P., Fructuoso, M.F.C., 2005. Aquatic birds as bioindicators of trophic changes and ecosystem deterioration in the Mar Menor lagoon (SE Spain). Hydrobiologia 550, 221–235. doi:10.1007/s10750-005-4382-0

Jiménez-Martínez, J., García-Aróstegui, J.L., Hunink, J.E., Contreras, S., Baudron, P., Candela, L., 2016. The role of groundwater in highly human-modified hydrosystems: a review of impacts and mitigation options in the Campo de Cartagena-Mar Menor coastal plain (SE Spain). Environ. Rev. 24, 377–392. doi:10.1139/er-2015-0089

Martínez-Alvarez, V., García-Bastida, P.A., Martin-Gorriz, B., Soto-García, M., 2014. Adaptive strategies of on-farm water management under water supply constraints in south-eastern Spain. Agricultural Water Management 136, 59–67. doi:10.1016/j.agwat.2014.01.010

Martínez-Fernández, J., Esteve-Selma, M.-A., Martínez-Paz, J.-M., Carreño, M.-F., Martínez-López, J., Robledano, F., Farinós, P., 2014. Trade-Offs Between Biodiversity Conservation and Nutrients Removal in Wetlands of Arid Intensive Agricultural Basins: The Mar Menor Case, Spain, in: Sven Erik Jørgensen, N.-B.C., Xu, F.-L. (Eds.), Ecological Modelling and Engineering of Lakes and Wetlands, Developments in Environmental Modelling. Elsevier, pp. 275–310.

Martinez-Fernandez, J., Fitz, C., Esteve-Selma, M.-A., Guaita, N., Martínez-López, J., 2014. Modelización del efecto de los cambios de uso sobre los flujos de nutrientes en cuencas agrícolas costeras: el caso del Mar Menor (Sudeste de España). Revista Ecosistemas 22, 84–94.

Morote, Á.-F., Olcina, J., Rico, A.-M., 2017. Challenges and Proposals for Socio-Ecological Sustainability of the Tagus–Segura Aqueduct (Spain) under Climate Change. Sustainability 9, 2058. doi:10.3390/su9112058

Pellicer-Martínez, F., Martínez-Paz, J.M., 2018. Climate change effects on the hydrology of the headwaters of the Tagus River: implications for the management of the Tagus–Segura transfer. Hydrol. Earth Syst. Sci. 22, 6473–6491. doi:10.5194/hess-22-6473-2018

Riis, T., Kelly-Quinn, M., Aguiar, F.C., Manolaki, P., Bruno, D., Bejarano, M.D., Clerici, N., Fernandes, M.R., Franco, J.C., Pettit, N., Portela, A.P., Tammeorg, O., Tammeorg, P., Rodríguez-González, P.M., Dufour, S., 2020. Global overview of ecosystem services provided by riparian vegetation. Bioscience. doi:10.1093/biosci/biaa041

Velasco, J., Lloret, J., Millan, A., Marin, A., Barahona, J., Abellan, P., Sanchez-Fernandez, D., 2006. Nutrient and particulate inputs into the mar menor lagoon (se spain) from an intensive agricultural watershed. Water Air Soil Pollut. 176, 37–56. doi:10.1007/s11270-006-2859-8

### 3.6.14 Planning

Most components of the pilot model are already operational. Nevertheless, there are various remaining tasks in order to better quantify relations between variables and add additional model components and relations to accurately simulate the multi sectoral impacts of different scenarios and transition pathways identified by the stakeholders. We plan to update and improve the agricultural nutrient export rates and equations based on a recently published report by the University of Valencia that uses the PATRICAL model to make a complete balance and propose management recommendations. This also includes taking into account, as much as possible, the nutrient concentrations in the aquifer, which will keep exporting nutrients to the lagoon after the management practices has been implemented due to the current high concentrations and this will delay the recovery of the lagoon (legacy sources).

We want to extend the set of socio-economic variables used as indicators and to that end, we need to keep looking for data and literature in relation to the economic and social impact of the different sectors.

We plan to add an outflow variable in the stock of yearly tourists to model decreasing numbers due to the Mar Menor degradation, and better quantify the tourism potential based on diverse touristic developments.

We plan to link the implementation of solar photovoltaic facilities with sea water desalination technologies for irrigation purposes in order to create a positive feedback loop between renewable energies and agriculture. The RE installed stock will be related to an economic profit which will also link to a new variable calculating the total economic profit from all sectors. Similarly, a new variable called total number of jobs from all sectors will be added.

In relation to climate change effects, we would like to include the effect of a higher number of extreme precipitation events in the export of nutrients and the impacts on coastal populations due to flooding. Besides, we will try to account for a higher water demand by croplands due to higher temperatures and evapotranspiration.

In relation to agricultural sustainable practices, we would like to include the effect of crop diversification and green covers on crop production and possibly in other ecosystem services.

# 4 Synthesis and next steps

In this report we have described how for the different MALs the CLDs resulting from the analysis in WP1 complemented with further MAL actor input were used to define the SD pilot model structures for each of the MALs.

In general, for the full implementation of the SD models the following steps are needed:

a) identify the main stock variables for each sector mind map/ CLD;
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.

As explained in the section on methodology (section 2) the development of the pilot models corresponds to the first three of these steps but some collection of data and models (d) is at times needed to assure that the retained structure is more than a mere hypothetical design. While some of the MALs indicate that they have indeed progressed (some of) their model development beyond the collection of data and models, some partners also plan to extend the scope of their models to include other problems identified in WP1 which ultimately will imply additional time needed to arrive at a final set of fully calibrated, tested and validated models that can be used for policy design and analysis and which are due by month 36 in the current project planning. In Table 11 we provide an overview of the status and planned next steps for the different MALs.

*Table 11: Pilot model development status for the MALs listing both the developed and planned pilot models.*

| MAL | Pilot models ready/ planned? | Additional pilot models planned? | Quantification of pilot models | Testing started? |
|---|---|---|---|---|
| **1** | 2/2 | No | Partial | Partial |
| **2** | 3/3 | No | Limited | No |
| **3** | 1/2 | No (1) | Full / No | Yes for 1 model |
| **4** | 4/4 | No | Partial | Limited |
| **5** | 5/5 | Yes (1) | Limited | No |
| **6** | 7/7 | No | Almost all | Partial |

As pilot models come in different sizes, complexity and detail a direct comparison of the pilot models for the MALs merely based on Table 11 is of limited value in establishing the status of progress made.

The WP4 leader assessment of the status is as follows:

- MAL1 has provided 2 pilot models. These are not operational but during the development for some parts data/equations were collected so that these can hopefully be fully implemented and tested. For testing and data collection support from the MAL actors will be requested. The pilot models that were developed do not address all the CLD topics that were identified in WP1. Consultation with actors and stakeholders is needed to check to what extent missing topics should still be included bearing in mind the project planning.
- MAL2 has 3 pilot models that have been defined as SD model structures. The MAL modelling team have collected data on most of the variables considered in the model but currently the models are not operational. As the proof of the pudding is in the eating the next challenge will be to find equations and data for the proposed structure and it is to be expected that spme of this will have to be revised depending on the availability of data and equations.
- MAL3 has fully developed an operational model for one of their problem domains (water balance) and has used this model in a few test runs. For the other problem domain (solute transport) the structure is to a large extend in line with the model already developed. Further development is therefore expected to be straight forward and the experience with the first model should help in arriving at an operational SD model. The MAL3 modelling distinguishes itself from the other MALS in that from onset the modelling team decided to use Vensim to reproduce the water balance results from previous quantitative mechanistic modelling exercises. As a water balance is a snapshot in time or an average over a period, it remains to be seen to what extend the proposed Vensim SD model will be able to correctly represent the dynamics of the water distribution over the different stocks and flows considered in the model. The big advantage of the MAL3 model is that quantification is straight forward due to the methodology chosen.

- While developing the SD pilot model structures MAL4 also defined equations so that the pilot models can be considered to be (almost) operational. The step to operational models should therefore be small but testing and model validation will have to prove that the equations/quantification envisioned during the pilot model development are able to reproduce observed dynamics.
- In MAL5, as in MAL2, SD pilot model structures were defined based on the WP1 CLDs, a large literature base and extensive interaction with the MAL actors and stakeholders. Quantification is currently limited so also for this MAL the challenge will be to collect the necessary data/equations for full implementation in the coming months. In view of the size of the proposed MAL5 model base, this will be a significant task. MAL5 also plans to extend their pilot models with an additional model. This model can be based on modelling in MAL1 (off shore wind parks) and has little bearing on the already defined model structures and can therefore be seen as parallel development which should not affect the rest of the model. In view of the deadline in month 36, focus on the 5 pilot models that have been defined seems however to be advisable.
- MAL6 produced the largest number of pilot models albeit it should be remarked that these in general are of a smaller scale and complexity with less feedback than those proposed by the other MALs. It is off course not an aim in itself to produce large and complex model structures and while the individual sector model components for MAL6 contain almost no feedback, the overall model structure does consider some intersectoral feedback. However, one of our concerns for MAL6 is that due to the rather simple structure the dynamics of the proposed SD models will not be able to reproduce all observed feedback in the system. Fortunately, the MAL6 pilot models are in a more advanced state than some of the other MAL models so that when the model is tested and/or model results are presented to MAL actors and stakeholders there will still be time to revise the model structure should this be necessary.

By month 36 the pilot model structures will have to result in a set of operational SD Models for Coastal-Rural Interactions for each of the MALs. Some of the models developed will be interchangeable and connectable and will concern relevant problems and activities for more than one MAL such as the transition to more sustainable agriculture, tourism or coastal eutrophication. Ultimately, the exchange of knowledge, data and models between the MALs is of key importance for the success of COASTAL. Based on the model structures used in the individual MAL SD models, generic patterns will be identified that can serve as generic tutorial models and become part of a Generic Coastal-Rural Modelling Toolbox for Business & Policy Analysis, to be maintained and further developed through the COASTAL knowledge exchange platform. A report on this toolbox is also planned by month 36 together with the operational SD models.

A general observation is that the translation of the causal loop diagrams into stock-flow model structures has been more demanding for the project teams than anticipated. For this reason, the progress of the modelling was included as a new risk in the Risk Management Strategy (COASTAL deliverable D25) to be addressed with additional support for the modellers, tutorial sessions, and hands-on assistance with the design and improvement of their models. *Ex post* the reasons for the difficulties during the pilot model development can be attributed to the limited experience of the modelling teams with System Dynamics combined with the lack of a fine grained, well defined methodology to develop such models from a CLD from the onset. While System Dynamics is not difficult and even taught in elementary schools, the development of suitable SD model structures based on the complex mind maps and CLDs produced in WP1 is not trivial. During kick off participants were handed several generic SD model examples and received an explanation of general SD principles. This was however clearly not enough to kickstart a successful SD model development process for most involved. Fortunately, and this is probably the most rewarding experience of the past year, none of those involved gave up or showed signs of “SD fatigue” but remained enthusiastic and eager to master SD modelling. Based on the lessons learned during the development of the pilot models, for the next phase up to operational models in month 36, development will be even more structured in smaller and better manageable steps. The following mid-term objectives for work package 4 until the end of the second reporting period (M36) have therefore been defined:

- M30: Full quantification of the pilot model structures
- M33: Calibrated, tested and validated models

To achieve the objectives up to month 36 the following strategy with supportive actions will be applied:

- A template for the next deliverable due M36 will be send out in M28 to clearly mark the track for the 9 month of development up to M36;
- To meet the mid-term objectives set out above a step-wise detailed methodology and templates will be elaborated that can guide the partners in achieving those objectives. These roadmaps will be provided in the beginning of the 3-month periods available for each of the intermediate objectives and will be further detailed during Skype sessions with the whole modelling team or, if required, the individual MALs.
- For the first objective, “Full quantification of the pilot model structures”, the course will be determined together with WP2 while for the month 33 objective for which “model testing, calibration and validation” is required WP3 and WP5 will be consulted.

# 5 References and further reading

De Kok, J.-L., Viaene P., Notebaert B., Karageorgis A., Panagopoulos Y., Kastanidi E., Destouni G., Kalantari Z., Seifollahi S., Maneas G., Lescot J.-M., Vernier F., Lazar L., Pop R., De Vente J., Martinéz-Lopez J. Model Scope and Feedback Structure. Deliverable D12. H2020-COASTAL. Grant Nr. 773782. https://h2020-COASTAL.eu/. 2019.

Deaton, Michael L. and Winebrake, James I.. Dynamic Modelling of Environmental Systems. Springer Science & Business Media. 2000. 194 p. ISBN 978-1-4612-7085-0.

Ford, Andrew. Modeling the Environment. 2$^{nd}$ ed. Island Press. 380 p. ISBN 978-1-59726-473-0.

Hovmand, Peter S. Community Based System Dynamics. Springer Science & Business Media. 2014. 104 p. ISBN 978-1-4939-4386-9.

Jørgensen SE and Bendoricchio G. Fundamentals of Ecological Modelling. 2001. Elsevier Science. 530 p. ISBN 0-080-44028-2.

Ruth, Matthias and Lindholm, James (Eds.). 2002. Dynamic Modelling for Marine Conservation. Springer Science & Business Media. 449 p. ISBN 978-1-4612-6544-3.

Sterman John D. Business Dynamics: Systems Thinking and Modelling for a Complex World, McGraw Hill, 2000.

Tiller, R., Kok, J.-L.d., Notebaert, B., Wouters, N., Stubbe, F., Motmans, S., Stubbe, W., Dauwe, S., Pirlet, H., Vernier, F., Lescot, J.-M., Jean -Luc Fort, Sabatié, S., Lazar, L., Timofte, F., Nenciu, M.-I., Golumbeanu, M., Destouni, G., Seifollahi-Aghmiuni, S., Kalantari, Z., Prieto, C., Chen, Y., Maneas, G., Kastanidi, E., Panagopoulos, I., Karageorgis, A., Guittard, A., BergJavier, H., Martínez-López, Vente, J.d., Boix-Fayos, C., Albaladejo, J., 2019. Sectoral Analysis of Coastal and Rural Development (D03), in: H2020, C. (Ed.), WP1 Multi Actor Analysis T1.1 - Sectoral Analysis of Coastal & Rural Development.

# Annex 1: check lists and other material provided for systematic model development.

## 1 Guidelines for Task 4.2 – Modelling of Land-Sea Interactions

**Objective**: to prepare for the multi-actor workshops and modelling workshop of General Assembly in Methoni - to be discussed during online Quarterly Progress Meeting I (March 6, 2019). The aim of this discussion paper is to clarify some modelling-related questions and put some issues on the agenda. The modelling workshop on Day 4 will be preceded by an introduction and modelling related sessions on Day 3.

**Proposed modelling guidelines (for general workflow see project description):**

- Use cleaned up Causal Loop Diagrams (CLDs) as model architecture – start from sector CLDs (see attached example of a CLD for farming at end of this document). CLDs provide more information on the feedback structure than mind maps and do this preferably using less detail.
- Appoint one or two core modelers for each MAL and organise quarterly online meetings (starting with modelling workshop in Methoni)
- Together the core modelers will develop a generic library of VenSim models addressing issues relevant for multiple MALs to facilitate the modelling, taking into consideration the added value for communicating with; this will save time that we can instead use for developing good applications and examples. Examples of generic stock-flow models: age-cohort model, business cycles, land pressure, COASTAL eutrophication, ….
- Collection of data (statistics, field data, …) should focus on historic calibration, initialization of stock variables, and model validation at the appropriate level of detail
- If necessary, we can use graphical (table) functions instead of equations to describe the relationship between variables. This functionality is supported by VenSim
- Organise models in multiple VenSim 'Views' with one view per sector, this will provide a better overview and make it easier for users to understand the model structure documentation and model user control – focus model output on existing and new Key Policy and Business Indicators (like KPIs)
- Focus the pilot model of the system (Milestone 4, due April 2020) on land-sea interactions as this is the topic of the project
- Use the Knowledge Exchange Platform for model exchange, maintenance and documentation, and as data repository (Open Data Pilot)

**Typical questions and possible answers (not exhaustive)**:

1. Why do we need models? Model simulations are essential because it is very difficult to understand the mid- and long-term impacts of policy and business decisions, particularly for complex systems with multiple interactions.
2. What do we include? Here it is important to have a clearly defined purpose for your model, regardless of whether it is a conceptual or fully quantified model. Just modelling the 'total system' without reason is not a good idea (Sterman, 2001). It is better to address a specific problem or topic with your model. For COASTAL this could be regional development and land-sea interaction, but also a narrower purpose – for example, how to develop a new business (seafood, agro-tourism, …) in the area. This model purpose will also help set the boundaries of the model. We will not model climate change, the world energy market etc. These will be input for your model as scenarios driving the model. What's to be included or not in the model and the time horizon will also depend on the model purpose.

3. Should we model the complete system or parts first? We need both. After we have decided what the complete system and its boundaries are (see point 1) we'll have to identify and understand the impact of land-sea interactions, and cross-sectoral interactions in this system. All the time we should keep in mind the purpose of the model (see point 1). We also need models for the sectors (to explain the sector dynamics). For example, how does a new business such as aquaculture develop over time?

4. How should we confront our stakeholders with our models? The best is to do this carefully and step-by-step. A complex diagram of the total system can be discouraging to them and may even raise criticism on the practical usefulness. A good way is to start from the sector problems, present the conceptual models for the sectors first, followed by a simplified diagram for the total system (showing the main feedback loops), and finally the diagram for the total system with all land-sea interactions. It's also good to use the functionalities for visualisation in VenSim (different colours for the sectors, fat arrows to highlight the feedback loops etc.)

5. When to use mental maps, mind maps, Causal Loop Diagrams and Fuzzy Cognitive Maps? Mental maps or mind maps are the diagrams developed during the sector workshops: the stakeholders defined their problems, priorities, obstacles and opportunities and helped us identify the causal linkages (positive and negative). Causal Loop Diagrams and Fuzzy Cognitive Maps (FCMs) are more polished and show the key state variables of the system and feedback structure of the system. The difference with CLDs is that in FCMs weights are assigned to each interaction (VenSim arrow) and FCMs can be used to generate scenarios. Stock-Flow models, finally, require more data, but are the best tool to examine the dynamics of the system because we can include time delays, threshold values, and non-linearity.

6. Why is system feedback important and how can we find the feedback loops? The dynamics of the system (linear or exponential growth, limited growth, collapse, …) can be explained from the internal feedback structure – some examples can be found in Deliverable D12. Feedback loops are quickly found in VenSim by selecting a variable and using the Loops tool (left menu bar).

7. Should we include human behaviour and other 'soft' variables and how can we do this? We should include these if they are important and were mentioned by the stakeholders – COASTAL follows a multi-disciplinary approach. Human behaviour (for example 'Social Cohesion') can be quantified on a 0-100 range, equations replaced with graphical functions. This is very common in SD modelling and always better than leaving out these variables (Sterman, 2001).

8. What happens if something important is overlooked in the mind map? We add it; it is normal for stakeholders to focus their mind map on what they consider important – system feedback is not their priority. Some interactions are implicitly assumed. The MAL modelling teams should clean up the mind maps into CLDs capturing the feedback explaining the problems raised by the stakeholders.

9. Should our models be developed from scratch? We will develop and exchange generic sub models, which can be adapted to the needs of the MALs to avoid duplicate work and make our modelling task easier. A good generic stock-flow model explains a historic behaviour of the system, is well calibrated, sensitive to changes in scenarios/policy settings, and has some documentation explaining its use.

10. How can we validate our models? The aim is to develop **evidence-based** solutions, using scientific data and expertise. WP4 (System Modelling) and WP2 (Knowledge Transition) will collaborate to collect the data needed to calibrate and validate the system models, set the initial conditions etc. These data will include statistics, but also time series and other output generated with other models. Tests to 'build confidence in the model' may include extreme condition testing, the sensitivity of model results for simplifying the model, and surprising behaviour testing (Forrester & Senge, 1980).

11. Why do we use VenSim? VenSim was already considered during the proposal stage. The free software VenSim PLE and cheap upgrade VenSim PLP are easy to use. For comparison of the functionalities see the comparison table. In addition, there is a free read-only version of VenSim, the VenSim Model Reader. The causal tracing and loop tracing tools of VenSim PLE are useful functionalities, in addition VenSim has functionalities for checking the model and units used (see User Manual). For FCMs we recommend MentalModeller. It's also possible to extract FCMs from a VenSim CLD, for processing in R or MatLab.

12. How will the models be used? System Dynamics models can be used for holistic analysis of systems with feedback, often referred to as 'policy analysis' (Sterman, 2001). Policy analysis is more than just adjusting model parameters, we will use our understanding of the system feedback to compare different solutions. This can also include changes to the feedback (changing model structure by removing or adding loops). The model application will be coordinated with WP3 (Business & Policy solutions) and WP5 (scenarios & transition pathways). Stakeholders can be expected to be more interested in the business and policy recommendations, i.e. well-documented examples, than the models themselves. Well-polished models could be made available for use with the VenSim Model Reader.

13. How do we avoid duplicate work in the MALs? It's important to control our budget for modelling and data collection. The COASTAL website and knowledge exchange platform will be used to exchange expertise, test models and used as a modelling forum. Project Task 4.3 is aimed at developing the generic structures – model constructs which can easily be exchanged and used for a different purpose (for example, a demand-supply model).

14. When should our models be ready? The sooner we start modelling the better – it is unavoidable that we will run into problems and by doing so we'll gradually be learn from our experiences and be able to improve the models. Task 4.2 runs until project month 36 (April 2021). We have two milestones: the completion of the pilot models (April 2020) and the operational models which should be ready for use by WP1 and WP3 by March 2021.

**Useful References and online resources on SD Modelling**


Deaton, Michael L. and Winebrake, James I. Dynamic Modelling of Environmental Systems. Springer Science & Business Media. 2000. 194 p. ISBN 978-1-4612-7085-0.

Ford, Andrew. Modelling the Environment. 2nd ed. Island Press. 380 p. ISBN 978-1-59726-473-0.

Forrester, J.W. and Senge, P.M. (1980). Tests for building confidence in system dynamics models. TIMS Studies in the Management Sciences 14, 209 – 228. http://myweb.ncku.edu.tw/~wtwang/course-SD/Forrester_Senge-1980.pdf

Hovmand, P.S. Community Based System Dynamics. Springer, New York. 2014.

Kim DH. Guidelines for Drawing Causal Loop Diagrams. The Systems Thinker Vol. 3(1), Pegasus Communications, 1992. http://www.thesystemsthinker.com/tstgdlines.html

Meadows D. Thinking in Systems. A primer. Earthscan, 2008.

MIT Readings: https://ocw.mit.edu/courses/sloan-school-of-management/15-988-system-dynamics-self-study-fall-1998-spring-1999/readings/

Ruth, Matthias and Lindholm, James (Eds.). 2002. Dynamic Modelling for Marine Conservation. Springer Science & Business Media. 449 p. ISBN 978-1-4612-6544-3.

Sterman John D. Business Dynamics: Systems Thinking and Modelling for a Complex World, McGraw Hill, 2000.

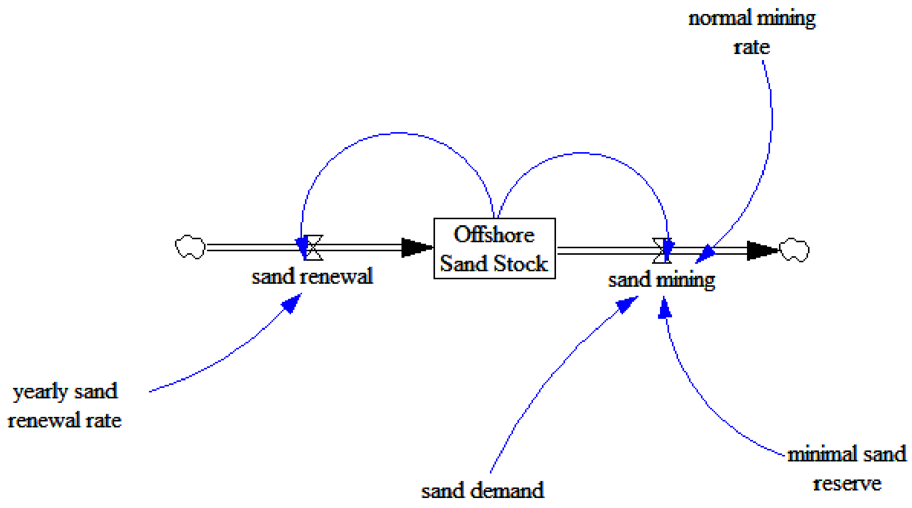
VenSim support https://vensim.com/support/

Voinov A. Systems Science and Modelling for Ecological Economics, Academic Press, 2008.

# 2 Inventory of model variables

Send to participants in November 2019. They were requested to inventory the variables in their models.

**Example: sand mining model**




| MAL | Topic | Stock variable (identify one) | Incoming driver | Flow variables | Parameters | Time resolution & horizon |
|---|---|---|---|---|---|---|
| 1 | Sand Mining | Sand Stock (ton) | Sand demand (ton/yr) | Sand renewal (ton/yr); Sand mining (ton/yr) | Sand renewal rate (1/year); normal sand mining rate (ton/year) | Month; (2020-2050) |

YOUR MODEL:

| MAL | Topic | Stock variable (identify one) | Incoming driver | Flow variables | Parameters | Time resolution & horizon |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
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# 3 VENSIM Model Progress Checklist

List provided in June 2020 to establish the status of the modelling for the different MALs. The list is also intended to guide the modelling teams as to which steps are required to arrive at the final model.

| | Check (yes/no) |
|---|---|
| **STOCK-FLOW MODEL** | |
| **Model boundaries and scope fixed** | |
| **Time horizon set** | |
| **Model drivers fixed and quantified** | |
| **Stock variables included** | |
| **Flow variables included** | |
| **Land-Sea Interactions included** | |
| **Policy and/or Business indicators fixed and included** | |
| **Feedback structure fixed** | |
| **Initial conditions of all variables defined** | |
| **Equations complete for all interactions** | |
| **Parameter settings included** | |
| **Model passes VenSim “Unit Check”** | |
| **Model passes VenSim “Model Check”** | |
| **Model running** | |
| **Model testing completed** | |
| **Multiple scenarios available and compared** | |
| **Comments added in model** | |
| **Model documented with a presentation** | |
| | |
| | |