Ref. Ares(2020)7686743 - 17/12/2020

COASTAL
Collaborative Land-Sea Integration Platform

Knowledge Transition

Deliverable D07

WP2 Knowledge Transition; T2.2 – Knowledge Transition
Lead beneficiaries: HCMR and SU

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Date of approval:	11/12/2020
Approved by Project Coordinator:	Jean-Luc de Kok
Date of approval:	14/12/2020
Planned due date of deliverable:	December 31st 2020
Actual submission date:	17/12/2020

H2020-RUR-02-2017	
Project number:	773782
Project duration:	1 May 2018 – 30 April 2022
Project coordinator:	Jean Luc De Kok, VITO
Project web site:	www.h2020-coastal.eu
COASTAL Knowledge Exchange Platform:	www.coastal-xchange.eu

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

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

History of changes			
Version	**Date**	**Changes made**	**By**
01	25.05.2020	Initial template is prepared	Samaneh Seifollahi
02	08.10.2020	Initial template is updated	Samaneh Seifollahi
03	21.10.2020	MAL3 section is completed as an example	Samaneh Seifollahi and Georgia Destouni
04	01.11.2020	Introductory sections are completed	Samaneh Seifollahi and Georgia Destouni
05	02.12.2020	General assessment is conducted	Jean-Luc de Kok, Peter Viaene, and Nele D'Haese
06	10.12.2020	Inputs from all MALs are included	Contributors from all MALs
07	11.12.2020	Synthesis of MAL inputs is included	Samaneh Seifollahi and Georgia Destouni
08	14.12.2020	Final approval is given	Aris Karageorgis and Jean-Luc de Kok
09-Final	16.12.2020	Final version for submission is prepared	Samaneh Seifollahi
10	17.12.2020	Finaly quality control and submission	Jean-Luc de Kok

Partnership:

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EXECUTIVE SUMMARY

The general objective of work package (WP) 2 in COASTAL is to develop quantitative data and scientific model constructs to support synergistic analysis of the land-sea interactions identified in WP1 for each Multi-Actor Lab (MAL). Modelling and data collection are usually parallel activities as model architecture points to data needs while data availability can be a limiting factor for model development. In this respect, WP2 is closely connected with WP4 - Systems Modelling, and supports: (i) quantifying physical, socio-economic and environmental land-sea interactions; (ii) making the existing and developed knowledge applicable in a System Dynamics (SD) framework; (iii) developing a basis for business and policy analysis in WP3 and for formulation of scenarios and transition pathways in WP5. As a consequence, this deliverable puts a strong emphasis on the architecture and progress of the SD models and the data needs for the six MALs.

Following Task 2.1 in WP2 and its Deliverable D06 (Model and Data Inventory – submitted in December 2018 and updated in October 2020), Task 2.2 aims to translate and synthesize available modelling approaches, their results and reported data, as outlined in the D06 report, into equations, parameter settings and quantitative input for SD model quantification in all MALs. The current report is the second deliverable of WP2 and summarizes different approaches used to make available data, and supporting models (other than SD models) and their results applicable for the SD model quantification in the various MALs during the past 26 months of the project (months 7-32).

The report includes an introduction of COASTAL, WP2, and Task 2.2 (sections 1 and 2), and highlights general knowledge transition needs within and across all MALs in this project (section 3). It also outlines various examples of data synthesis and translation related to MAL2 and MAL3 (section 3), developed by Stockholm University (SU) - task leader and co-leader of WP2, leader of the Swedish MAL3, and co-leader of the Greek MAL2 - and discussed with other MAL leaders in different meeting occasions of COASTAL. The report continues with general reflection and conclusions (section 4) based on the difference specific MAL sections (section 5). This includes summarizing scenario analysis strategy for each MAL and whether and how this can be related to key policy frameworks of the European Green Deal, the United Nations (UN) sustainable development goals (SDGs) in Agenda 2030, the shared socioeconomic pathways (SSPs) of global climate change scenarios, and marine spatial plans (MSP) - if/as currently applicable for each MAL. Separate sub-sections within section 5 are devoted to each MAL, and present available quantitative information and describe how and to what degree different SD sub-models are quantified.

Depending on the complexity of MAL-specific problem scopes and land-sea interactions identified in their causal loop diagrams (CLD), different MALs are currently at different levels with their SD modelling and its quantification. Also, availability of data and supporting model results differ for different SD sub-models in and across the MALs. Many of the SD sub-models in most of the MALs are only partially quantified and some are not yet quantified. This explains the different information levels included in the different MAL sections of this report. MALs have planned various types of scenarios to address implications of existing uncertainties for land-sea interactions. Possible scenarios for testing are mostly related to: the two European Green Deal topics “Protecting nature and biodiversity” and “From farm to fork and healthy food system”; the two SDGs 6 (Clean water and sanitation) and 13 (Climate action); some of the SSPs through relations to scenarios of

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climate, sustainability and land-use changes; and specific topics under the regional MSPs related to the MALs. However, testing possibilities for these scenarios, which can further support WP3 and WP5 tasks of developing MAL-specific business roadmaps and transition pathways, will greatly depend on the continued development and quantification of the SD models in the different MALs. SD modelling and its quantification, as an interlinked project activity between WP2 and WP4, will continue until project month 36 (April 2021) when the Deliverable D14 of WP4 will report on operational SD models in the MALs, based on further quantification updates from the state of the SD models at the time of the current report preparation for WP2.

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List of Acronyms

AP Agricultural Production
CCWI Cross-Catchment Water Inflow
CCWE Cross-Catchment Water Outflow
CLD Causal Loop Diagram
DDBR Danube Delta Biosphere Reserve
DDBRA Danube Delta Biosphere Reserve Authority
DIN Dissolved Inorganic Nitrogen
DMP Data Management Plan
EC European Commission
EU European Union
FA Freshwater Aquaculture
FFS Freshwater Fish
FFW Freshwater Fishermen Welfare
FW Farmers' Welfare
gw Groundwater
IOA Input-Output Analysis
MA Marine Aquaculture
MAL Multi-Actor Lab
MAS Marine Aquaculture Stock
MFS Marine Fish Stock
MFW Marine Fishermen Welfare
MSP Marine Spatial Plan
MWS Municipal Water Supply
NBS Nature-Based Solution
ORDP Open Research Data Pilot
SD System Dynamics
SDG Sustainable Development Goal
SF Stock-Flow
SLM Sustainable Land Management
SPAMI Specially Protected Area of Mediterranean Importance
SSP Shared Socioeconomic Pathways
SSW Subsurface Water
SW Surface Water
SWAT Soil and Water Assessment Tool
SWIR Seawater Intrusion Risk
TN Total Nitrogen
TP Total Phosphorus
UCWW Unconnected Coastal Wastewater
USR Urban Surface Runoff
UN United Nations
WP Work Package
WWTP Wastewater Treatment Plant

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1. INTRODUCTION

COASTAL is a unique collaboration of coastal and rural business entrepreneurs, administrations, stakeholders, and natural and social science experts. In COASTAL, local and scientific knowledge are combined to identify problems and develop practical and robust business road maps and strategic policy guidelines aiming at improving land-sea synergy. A multi-actor approach is followed to analyze the social-environmental and economic land-sea interactions in a System Dynamics (SD) framework (Sterman, 2000), taking into consideration feedback mechanisms on coastal and rural development. The project is organized around interacting Multi-Actor Labs (MALs), combining tools and expertise for six case studies representing the major coastal regions in the EU territory (Figure 1). In each MAL local actors and experts participate in collaborative exercises to identify problems, analyse the causes, propose and discuss solutions, and validate and interpret the impacts of various local/regional change/development and policy decisions. This has been conducted through a range of modelling practices from qualitative conceptualization to quantitative SD modelling (Figure 2).

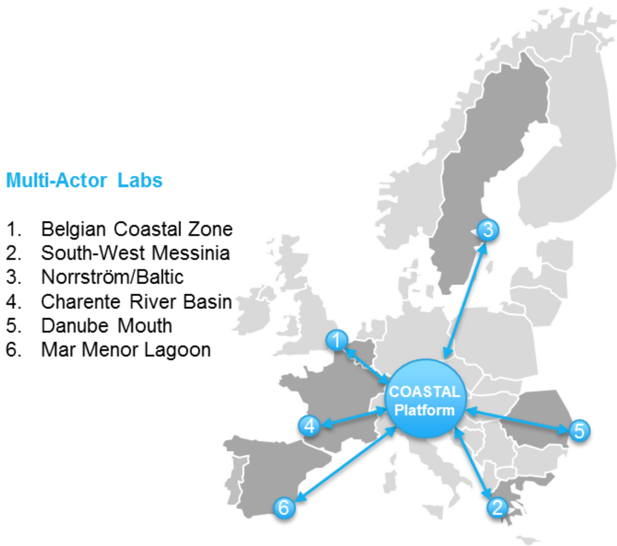

Figure 1. Network of interacting Multi-Actor labs (MALs) on the COASTAL platform.

The general methodology of COASTAL is based on integration of a participatory multi-actor approach (Medoza and Prabhu, 2006; Stave, 2010; Hovmand, 2014) as qualitative analysis, and an evidence-based quantitative analysis. As shown in Figure 2, this is an iterative process, starting with identification of problems and creation of mental maps during interactive workshops with actors to conceptualize a structure of key feedback in the land-sea system of each case study. These mental maps are based on hypotheses of the causal interaction dynamics underlying the addressed pressing problems in each coastal case study.

In the quantitative SD model analysis, available social-environmental models and model results, statistics, field and experimental data are translated into mathematical equations and graphical response functions, quantifying the land-sea interactions identified during the workshops. SD model validity is assessed by qualitative and quantitative testing, considering the model structure, simulated systems dynamic behavior, and policy or business implications of model results. This quantitative analysis and its outcomes

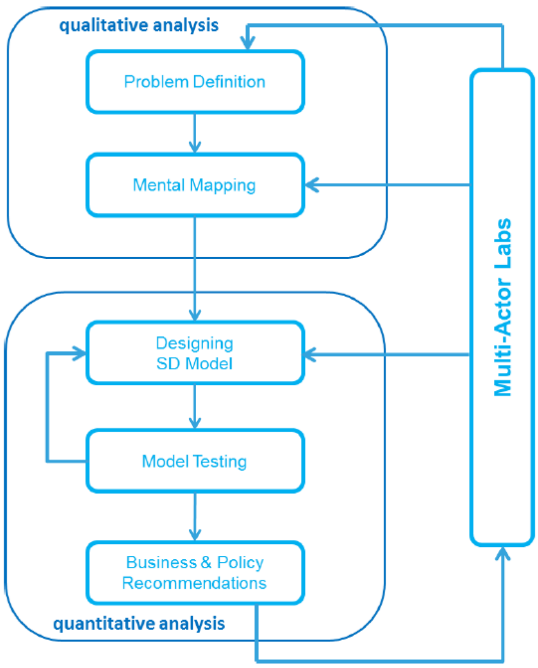

Figure 2. COASTAL workflow for qualitative and quantitative analysis in Multi-Actor Labs (MALs).

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aim to support development of robust business and policy decisions, taking into account the impacts of possible local/regional developments/changes (such as, climate change, population growth, land-use changes, etc.).

COASTAL is organized around interacting work packages (WPs) as shown in Figure 3, and different WP tasks with associated deliverable reports are conducted in all MALs. This report is the second deliverable of WP2, and it summarizes the outcomes of the second task of this WP for all MALs. The general objective of WP2 is to develop the quantitative data and scientific model constructs needed for synergistic analysis of key rural-coastal interactions identified through the qualitative analysis in WP1. The data and supportive models need to be translated to an appropriate level of detail and complexity for being able to provide a quantitative basis for further strategic business and policy analysis. As such, the main focus of WP2 is on the translation of existing data and models for quantification in the SD models of relevant social-economic, physical, and environmental interactions of the land-sea system in the different MAL case studies.

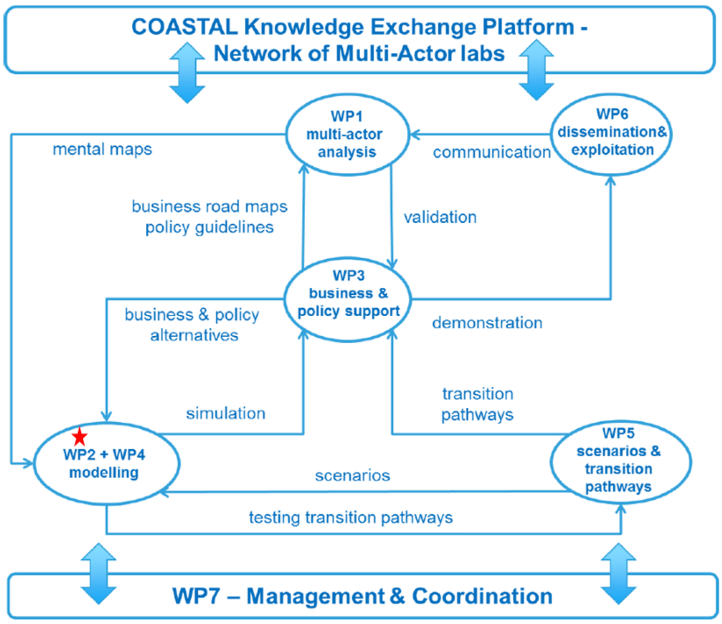

Figure 3. Project architecture presenting major work package (WP) exchanges with WP2 being highlighted with a red star as the relevant WP to this deliverable report.

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2. ROLE OF DELIVERABLE

2.1 Scope and objective

As part of quantitative analysis, WP2 - coordinated by Hellenic Centre for Marine Research (HCMR) and Stockholm University (SU) - supports WP4 in formulation of SD model equations and quantification of input and boundary condition variables to describe the modelled interactions between system components and associated model parameter settings. Three tasks with their associated deliverables are included in WP2 as:

i. Task 2.1. Data and model base (COASTAL Deliverable D06. Data and model inventory) – coordinated by HCMR
ii. Task 2.2. Knowledge transition (COASTAL Deliverable D07. Knowledge transition) – coordinated by SU (current report)
iii. Task 2.3. Confidence building (COASTAL Deliverable D08. Model validity) – coordinated by Vlaamse Instelling voor Technologisch Onderzoek N.V. (VITO)

The objective of Task 2.2 (months 7-32 of the project period) is to synthesize available data, other supporting models (than SD models) and their results for each MAL. An inventory of these is provided in Deliverable D06 report from December 2018 (the first deliverable in WP2 – associated with Task 2.1), and its further update in October 2020 (based on actual SD model development and quantification carried out until then). Task 2.2 aims to translate the further use of the data, models and model results outlined in the Task 2.1 inventory into the equations and initial/boundary condition and parameter settings in the SD modelling that quantifies key land-sea feedback mechanisms for the problems in focus for each MAL. The outcomes of the knowledge transition synthesized in and provided from Task 2.2 for and across the MAL-specific SD models developed in WP4 will support the formulation and testing of change/development scenarios as part of WP5, and the development of business roadmaps and policy guidelines for each MAL as part of WP3.

COASTAL consortium has agreed to participate in the Open Research Data Pilot (ORDP) of Horizon 2020[1]. The ORDP follows the principle of “as open as possible, as closed as necessary” and focuses on encouraging sound data management as an essential part of best research practice. Based on COASTAL data management plan (DMP), information collected by MALs in WP2 to support the SD model quantification in WP4, as well as newly generated model results in the project, will be harmonized following the principle of findable, accessible, interoperable, and reusable (FAIR)[2]. This harmonized information includes references to existing peer-reviewed scientific, measured, and reported data and published supportive modelling approaches. Clear explanation will also be included of possible reasons for publishing information under restrictions (De Kok et al., 2018 – updated in 2020).

2.2 Deliverable structure

This deliverable describes the process of synthesizing available data and supportive models (and/or their results) for the SD model quantification in each MAL. After a general introduction of the COASTAL project and its workflow, where the interaction of WP2 with other WPs is addressed (section 1, Figure 3), the report

[1] https://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-oa-data-mgt_en.pdf
[2] https://www.force11.org/group/fairgroup/fairprinciples

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follows an explanation of the deliverable's role in the project (section 2), and an outline of requirements of knowledge transition in going from qualitative to quantitative analysis (section 3). Section 3 also provides some concrete examples of possible knowledge transition opportunities from SD model quantification in one MAL to related quantification, or guidance of such quantification, also in other MALs. The examples draw from work in the Swedish and Greek MALs, which most of them also previously presented and shared with other MALs on different COASTAL meeting occasions.

Section 4 synthesizes and summarizes for the different MAL case studies, the main problems addressed in the SD modelling for each MAL, the types of change/development scenarios that can be investigated by the SD modelling, and the relation of the latter to main topics and scenarios associated with some key overarching policy frameworks at regional and EU levels. Section 4 also discusses general key aspects of the SD model quantifications in the MALs, and how they may support further WP3 and WP5 work on development of business roadmaps and overall scenario analysis, respectively.

Section 5 further details the SD sub-model quantification for each MAL, with each MAL sub-section providing the following case-specific information:

- A brief introduction to the case and identified/selected problems for SD modelling;
- An overview of the developed SD (sub-)models, their problem focus, and their quantification status at the time of preparation of this deliverable;
- Due to the complexity of land-sea interactions in most of the MALs, various SD sub-models are developed to address different problems and associated sector interactions in each MAL. For each SD sub-model, following information are then specifically provided:
  - An overview of the land-sea interactions and feedback structures considered in that SD sub-model, including a table of main variables, parameter settings, and stock-flow (SF) structure;
  - An outline of data, supportive models, and other type of model results used for quantification of that SD sub-model, and the translation process into equations as feedback response functions.

- A synthetic reflection on the quantification process for all SD sub-models in each MAL, addressing the main issues and possible data/knowledge gaps for the SD sub-model quantifications;
- An overview plan, summarized in a table for each MAL, for how the developed SD sub-models are to be used for analysis of relevant local/regional change/development scenarios and how these relate to key overarching policy frameworks;
- A list of references for the quantitative and other information outlined and used in the SD model quantification for each MAL.

The report template has been prepared by the task leader SU, discussed with WP2 and task co-leader HCMR, and tested on the Swedish MAL to provide sufficient guidelines for the input of other MALs. The main challenge in preparing this deliverable report was that the different MALs are currently at different levels of progress with their SD modelling. Due to the complexity and range of problem scopes in and across the MALs, development of SD sub-models differs in terms of degree of model quantification completion, associated data collection and model testing, resulting in different information levels (for SD model equations, non-linear functions, parameterization, etc.) for the different MAL sections.

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3. KNOWLEDGE TRANSITION

3.1 General knowledge transition needs

Existing research and policy primarily address issues from either a coastal- or a land-based perspective, making effective land-sea integration difficult due to fragmentation and lack of harmonized information. There is also often insufficient communication between researchers, planners and local actors for developing an integrated approach to utilize all available information and meet coastal-rural challenges, threats and opportunities collaboratively, sharing a joint holistic perspective.

COASTAL adopts an iterative participatory multi-actor approach, combining qualitative analysis with quantitative SD modelling, as shown in Figure 2, to provide the opportunity of knowledge transition among local actors and different MALs. The outcomes of qualitative analysis of land-sea problems and associated interactions are used as a basis for SD modelling to quantitatively analyze dynamics and nonlinear behaviors in complex systems and understand possible counter-intuitive responses to business and policy decisions. The SD modelling is end-user oriented for relevant knowledge transfer on system behavior, and the graphical support of the Vensim software platform[3], used for SD modelling in COASTAL, enables combination of local actor knowledge and scientific expertise in joint validation and interpretation of relevance for business roadmap and policy development.

Furthermore, it is important to understand knowledge that encompasses data, third party models and the shared expertise of stakeholders and experts. With respect to data, a distinction can be made between numerical data (statistics, projections, etc.), written data (reports, procedures, etc.) and mental data (storylines, perceptions, etc.) (Forrester, 1980; Sterman, 2000). The abundance and information of mental data by far exceeds that of written data which exceeds that of numerical data. This deliverable primarily focuses on the numerical data to support the SD modelling for the MALs. However, identifying and collecting these data also depends on effective communication with the experts involved in the project and their willingness to share their expertise (i.e. exploiting their mental data).

3.2 Quantification examples of possible general/transferable relevance

The data and model inventory developed in 2018 and updated in 2020 as part of WP2-Task 2.1 includes relevant available data, models and model results for use in the SD modelling of each MAL as part of WP4. The objective of WP2-Task 2.2 is to outline translation and synthesis of such information into equations and parameter settings in the SD modelling of the different MALs. The SU team, as task leader in WP2, lead partner for the Swedish case of MAL3, and co-lead partner for the Greek case of MAL2, has extracted and outlines below some examples of possible cross-regional such synthesis and translation, based on reported, validated results in peer-reviewed publications related to MAL2 and MAL3. Most quantification examples outlined below have also been presented and discussed with partners during the 2nd and 3rd General Assemblies and other meeting occasions of COASTAL to provide insights and transition of knowledge for quantification problems of possible relevance also for other MALs. In the following, the examples are structured and summarized under different main topics; it should be noted that, so far, these are only to

[3] https://vensim.com/

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some degree used for parts of MAL2/3-specific SD model quantification, and they are outlined here as examples of quantification aspects that work as directives for model development by other MALs, as well as for cross-MAL model exchanges, such as quantifying variable interconnections (WP4-Task 4.2) and/or validating feedback structures in the SD models (WP2-Task 2.3 and WP4-Task 4.3).

– **Nutrient loads to the sea from human activities and after retention on land**

Levi et al. (2018) report generalized estimates, and a quantification approach to arriving at these, of nutrient inputs to, retention in, and resulting delivery factors and loads from hydrological (sub)catchments of various scales, using a data-driven screening methodology based on commonly available monitoring data for water discharges and nutrient concentrations (Figure 4a-b). They have further reported regression relationships with high degree of correlation between nutrient concentrations and population density or farmland share found in and across Baltic and Balkan regions (Figure 4c-f); nutrient loads are also determined from these relationships, by definition, as the product of concentrations and associated water discharges. With population density and farmland share constituting common socio-economic indicators, such relationships, found to apply in various regions, may also be useful for nutrient-related quantifications in the SD modelling of different MALs.

Another publication example also reports an approach to accounting for how various features in a landscape, such as wetlands, lakes, and source-to-coast pathway length, are regulating the landscape ecosystem service of retaining waterborne nutrient and thereby decreasing nutrient loading to the coast (Quin et al., 2015). Such information can also be useful for nutrient-related SD model quantifications in different MALs.

– **Nutrient legacies and their contribution to water quality issues**

Legacy sources, accumulated over time in the subsurface parts of landscapes (soil, groundwater, sediments) from past-to-present nutrient releases at the land surface, have been found to contribute greatly to current nutrient loading to surface and coastal waters in various parts of the world (Basu et al., 2010; Destouni and Jarsjö, 2018; McCrackin et al., 2018; van Meter et al., 2018). This also includes and has been specifically reported, explained and quantified for the MAL3 case study (Darracq et al., 2008; Destouni et al., 2010). Destouni and Jarsjö (2018) have mechanistically derived and reported a general quantification approach and an associated diagnostic test to determine the importance of nutrient concentration and load contributions from subsurface legacy sources in comparison with that of active surface sources, based on distinctly different types of behaviour exhibited by nutrient (tracer, pollutant) concentrations and loads from these two types of sources when plotted against corresponding water discharges (Figure 5). With nutrient concentrations and associated water discharges being commonly available monitoring data in many coastal regions, the general approach and diagnostic testing proposed by Destouni and Jarsjö (2018) may be useful for related SD model quantification in different MALs.

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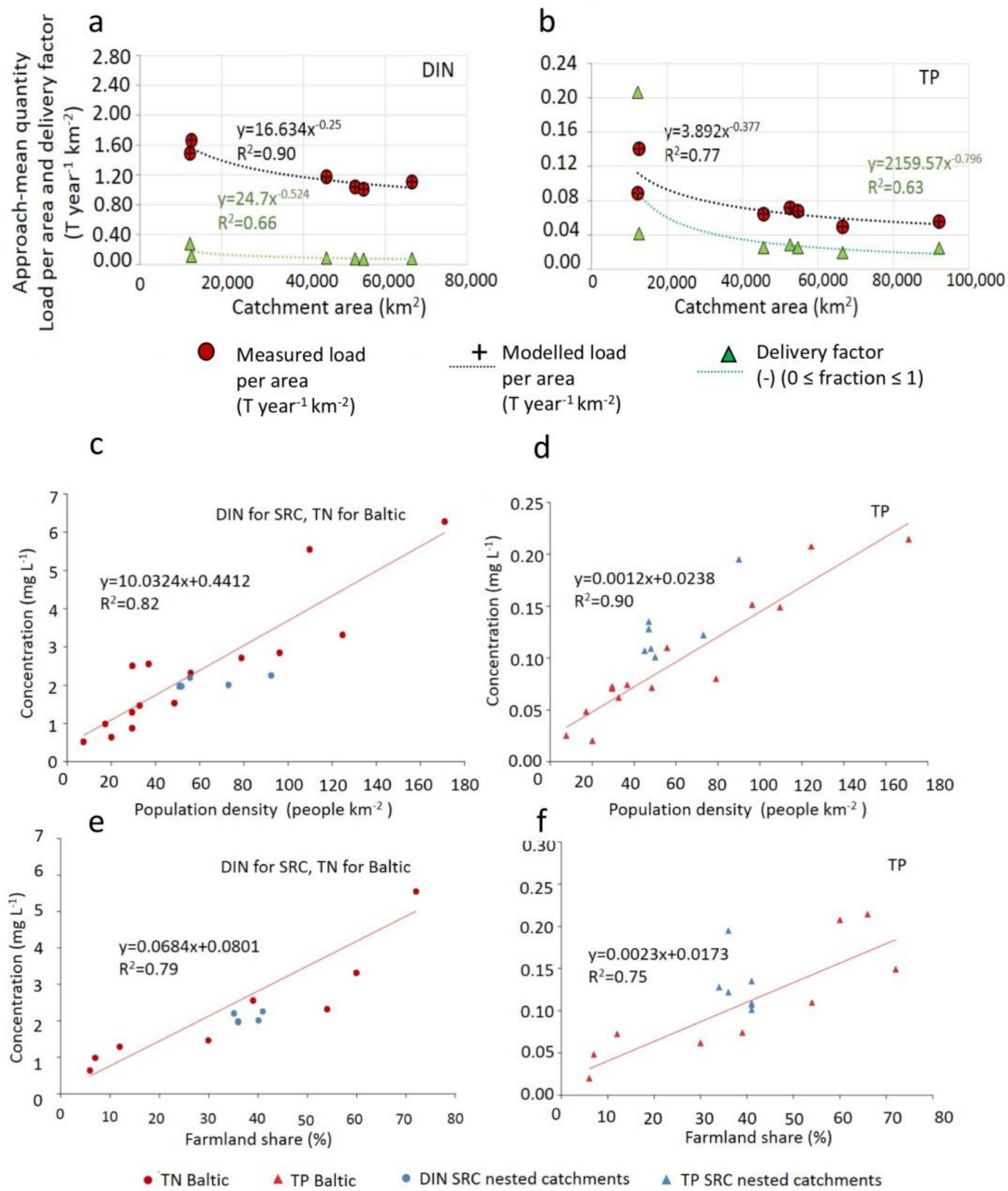

Figure 4. Annual average dissolved inorganic nitrogen (DIN) and total phosphorus (TP) loads per unit area and delivery factor versus sub-catchment/catchment scale (area) (a, b); DIN, total nitrogen (TN) and TP concentrations in the Baltic and Sava river catchment (SRC) versus population density (c, d) and farmland share (e, f). Source: Levi et al. (2018).

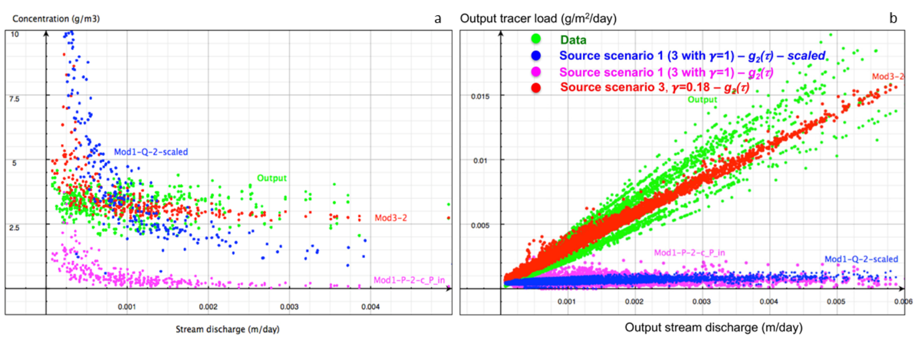

Figure 5. Data-given (green symbols) and model-based (other symbol colors) results of (a) concentrations and (b) loads of monitored chloride as a tracer, plotted versus area-normalized water discharge (runoff). Through mechanistic model derivation. Destouni and Jarsjö (2018) showed that model results for any tracer/nutrient/pollutant will exhibit very different concentration-vs-discharge (a) and load-vs-discharge (b) behavior, which is much more consistent with available data (green symbols), if dominant concentration and load contributions are from subsurface legacy sources

(red symbols) than if they are from currently active surface sources (blue and purple symbols, representing different types of models for active surface sources. Source: Destouni and Jarsjö (2018).

– **Change in coastal seawater intrusion due to climate and/or inland water-use changes**

Koussis et al. (2012; 2015) have derived and reported relatively simple general analytical solutions for estimating seawater intrusion into fresh coastal groundwater (Figure 6a). Mazi et al. (2016) used these solutions for further development of a simple screening-level regional model framework (Figure 6b) for general estimation of region-average proximity to thresholds of critical seawater intrusion under human pumping of fresh coastal groundwater (and change in this from past, through current, to possible future practices) relative to annually renewable groundwater recharge (as affected by climate change to shift from past, through current, to future conditions). This relatively simple framework may be useful for SD quantification related to seawater-intrusion problems in different MALs.

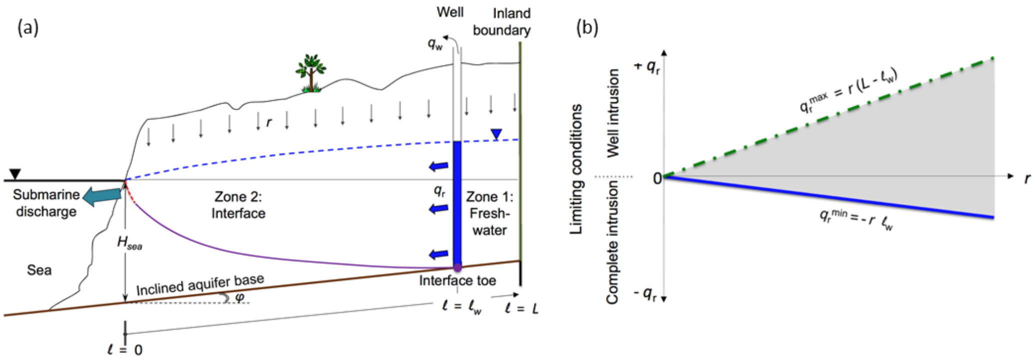

Figure 6. Schematic representation of (a) seawater intrusion (purple line, with mainly seawater to the left of it) into fresh coastal groundwater (right of purple line); (b) region-specific determination of maximum possible seaward groundwater flow, q_r^{max}, under zero pumping withdrawal of fresh groundwater, and minimum seaward groundwater flow, q_r^{min}, that must remain in the aquifer after pumping wells and their fresh groundwater withdrawal to avoid critical seawater intrusion into the wells. These regional limits depend on annual groundwater recharge rate (r) and characteristic weighted mean pumping well location (l_w) relative to the coastline and the total length extent of the coastal aquifer (L) in each region. Source: Mazi et al. (2016).

– **Freshwater flux changes under agricultural irrigation developments and climate change**

For assessment of main freshwater flux changes under both climate change and agricultural irrigation developments, Destouni and Prieto (2018) have developed, and also applied, and validated specifically for the MAL2 case study, a data-driven approach based on the overarching constraints of fundamental water balance in hydrological catchments (Figure 7). The approach considers flux changes between any two climatic time periods, with changes in climate and irrigation water use between them, to estimate water-balance constrained associated shifts in runoff and evapotranspiration flux changes between the periods (and uncertainty bounds for these estimates, based on underlying data availability). This approach (outlined further in Figure 7) can also be adapted and may be useful in other MALs for related SD quantification and/or future scenario analysis of main freshwater fluxes and their changes under different development scenarios.

– **Coastal wetland conditions under human intervention and climate change**

Maneas et al. (2019) and Manzoni et al. (2020) have developed data-driven and water-balance based modelling approaches for assessing impacts of human interventions and climate change on coastal

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wetland/lagoon conditions, as schematically illustrated in Figure 8. These approach developments have been applied to the MAL2 case study and associated SD model quantification, to support evaluation of flux, quality ecosystem condition changes over different time periods. Analogous developments may be useful for SD model quantification of related change pressures on coastal wetlands/lagoons also in other MALs.

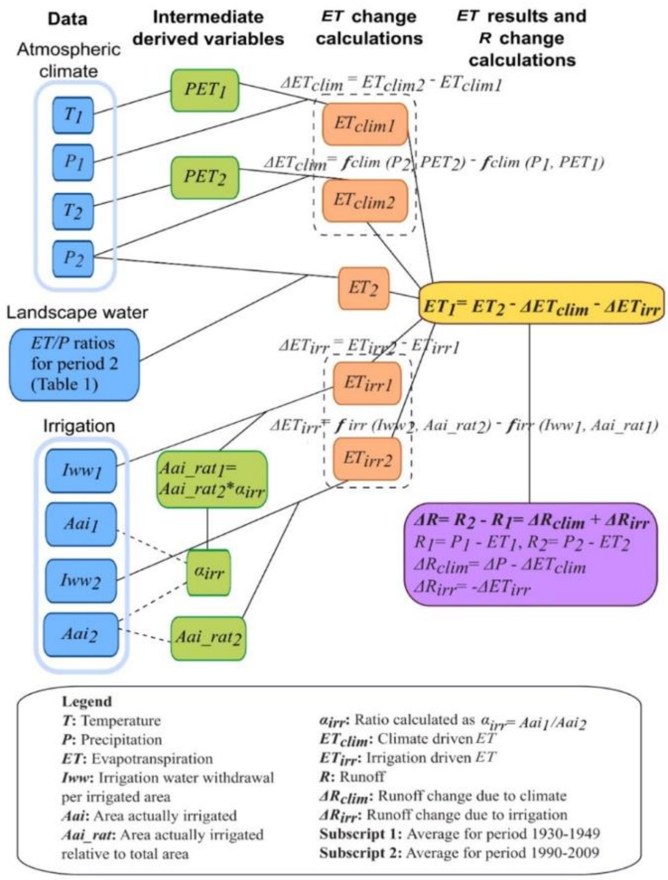

Figure 7. Schematic illustration of approach for assessing long-term changes (Δ) in average evapotranspiration (ET) and runoff (R) between different climatic time periods. The types of data used in this assessment approach are highlighted in blue (with specific extracted variables in blue boxes) on the left. The green boxes show intermediate derived variables, related to various components of change in actual ET outlined in red boxes and synthesized in the yellow box on the right. The lilac box shows final synthesis for estimating corresponding components and total change for R. Source: Destouni and Prieto (2018).

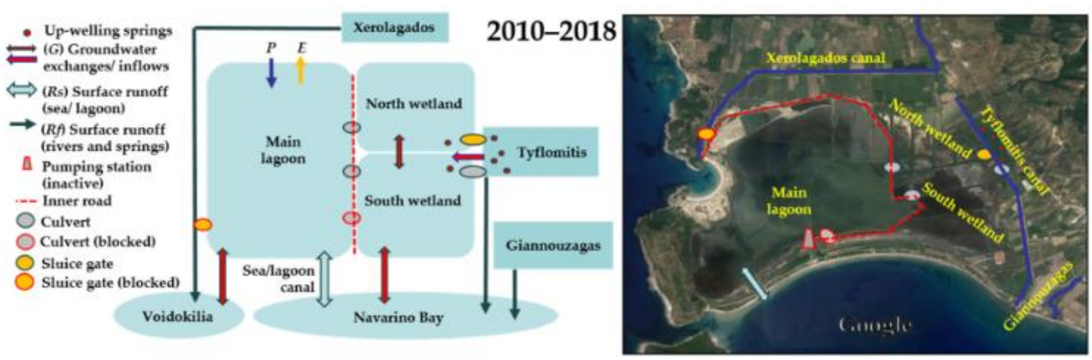

Figure 8. Schematic representation of natural and human-driven water flux exchanges (left) in the case of Gialova Lagoon/wetland of MAL2 (Google Earth image, right). Modified figure based on Figure 5 in Maneas et al. (2019).

4. OVERARCHING CROSS-MAL SYNTHESIS AND DISCUSSION

The six COASTAL MALs are located in major European coastal areas and represent different geographic scales from the local, through regional, to the international level (Table 1). They differ in demographic structure, degree of economic development, urbanization and industrialization, and social and environmental problem contexts. Thus, data and model support conditions, expectations and target sectors are different across the MALs. Different problems and associated land-sea interactions in focus for SD modelling in each MAL are summarized in Table 1. These problems cover a wide range of socio-economic and environmental issues, created and developed over time in these coastal areas, including land-based spatial planning, local/regional sectoral developments and their competition for resources, services and job market, various degrees of education and training to support innovative sectoral (mainly agricultural) practices, more or less excessive use of agricultural fertilizers and associated level of ecosystem and environmental degradation, various water-related (quantity and quality) problems and freshwater-seawater interactions in coastal areas, for example regarding groundwater extraction with increased seawater intrusion risk, and different existence/implementation of supportive local/regional/international plans and policies. These problems have been described in previous COASTAL Deliverables (Kastanidi et al., 2018 with an update on 2020; De Kok et al., 2019; Tiller et al., 2019b; Viaene et al., 2020) and are updated and further specified here, as summarized in Table 1 according to the SD modelling progress in the different MALs.

Table 1. Overview of MALs, their spatial scales and key addressed problems and associated land-sea interactions considered in the SD modeling of each MAL.

Country	European Sea	Specific MAL	Spatial scale	Key problems and associated land-sea interactions in the MAL SD modelling
Belgium	Southern North Sea	MAL1. Belgian Coastal Zone	Regional scale (1000 km2) with a 60 km coastline, focus on Ostend-Bruges area and hinterland (Province West Flanders)	Limited water resources and decreasing surface water quality have put pressure on the traditional activities in the rural hinterland. Increased salinization is another challenge especially for traditional agriculture. Furthermore, the dense use of coastal space for tourism and other economic activities calls for innovative solutions exploiting opportunities in the hinterland. Gentrification of farming land puts pressure on the food production capacity and opportunities for starting a farm. Negative and positive land-sea interactions are physical (eutrophication and salinization), economic (ports, services and employment related to offshore energy) and social-cultural (gentrification).
Greece	Eastern Mediterr-anean sea	MAL2. SW Messinia	Local-Regional (< 200 km2)	The main economic activities (agriculture and tourism) and the environmental status of the protected Gialova wetland/lagoon are depending on groundwater availability. At present, the wetland suffers from limited freshwater inputs and is also affected by the waterborne nutrients and olive mill wastewaters. Land-use competition between the main economic activities and high seasonality of the tourism sector put temporal pressures on local waste and wastewater treatment facilities. An overall lack of coordinated collective actions is also another problem in the region. The SD modelling focuses on the water availability issues which are related to these problems.

Sweden	Baltic Sea	MAL3. Norrström /Baltic Sea	Multi-scale Local-regional land-coast scale (around 50 x 1000 km2) The whole Baltic Sea land-coast scale (around 2000 x 1000 km2)	Natural-system and sectoral water availability and associated water-quality related waterborne nutrient load exchanges among the natural systems and sectors and to the coast (represents freshwater, phosphorus and nitrogen land-sea interactions), as well as for seawater intrusion interactions (of fresh and sea water) at the coast. SD modelling focuses on the local-regional land-coast scale.
France	Atlantic region	MAL4. Charente River Basin	Regional (10 km2)	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. water resources, and climate change consequences such as water shortages more severe droughts and potential intrusion of saline water. Land-sea interactions: - High dependence of downstream activities on upstream activities in terms of water quantity and quality - The attractiveness of coastal areas amplifies the increase and changes of population - Summer tourism causes coastal congestion with a growing demand for drinking water and needs for water treatment plants of capacities. - The development of ports relies on inland agricultural production. - Diversification of crops are diversified; ports should adapt their activities. - Climate change will impact coastal zones, coastal farmland, and the need to develop adapted agriculture and tourism in these areas.
Romania	Black Sea	MAL5. Danube Mouth	Local-Regional (1000 km2)	Sustainable development of the Danube Delta Biosphere reserve and its marine waters (Black Sea) in relation with pollution from main pressures from agriculture, fishery, tourism, rural development. SD modelling is focusing on: - 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.

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Spain	Western Mediterr-anean sea	MAL6. Mar Menor Coastal Lagoon	Regional (1200 km2)	Water scarcity, high demand of water by agriculture, high dependency on the Tagus-Segura water transfer. Illegal groundwater extraction and presence of illegal irrigated agricultural areas. Excessive use of fertilizers in irrigated agricultural areas, together with lack of nutrients retention measures, lack of training on the use of fertilizers and insufficient enforcement of regulations. Mar Menor degradation mostly by agricultural nutrients input. Pollution of surface water and coastal lagoon by brine wastes. Low economic diversification with dominance of the agricultural sector. High tourism seasonality and insufficient coastal and rural off-season recreation activities.

As explained in section 2.2, the MALs are at different stages of their SD model development and/or its quantification, due to various degrees of scope and complexity in the problems selected for SD modelling. Model development requires data collection to test and assure model structure and implement quantitative scenario analysis. However, SD sub-models of some MALs are not yet operative and still lack some quantitative information. Table 2 provides an overview of the number of different considered SD sub-models, and their development and quantification status in the MALs. Depending on the problem scope and complexity of the stakeholder analysis (Tiller et al., 2019b), the SD sub-models can and should only address a selection of (quantifiable) topics and problems included in the MALs' causal loop diagrams (CLDs) to address those problems in a meaningful manner. At the stage of completion of this deliverable, several of the sub-models were only partially quantified or being revised significantly based on feedback of the actor partners and stakeholders involved in the project (e.g., all sub-models in MAL1 and MAL6), while some are not yet quantified (e.g., sub-models in MAL2 and MAL5). In some MALs, the structure and parameter settings of fully or partially quantified sub-models may still change/extend, based on stakeholder and local expert feedback (e.g., in MAL2 and MAL4) leading to possible new variable and interaction considerations, and needs for associated supplementary data and quantitative information, and possible re-structuring and further quantification efforts in the coming months until April 2021 – when the SD modelling should be finalized in all MALs. This highlights the complexity of participatory modelling and difficulties in data collection and availability when working on a broad range of diverse problems within and across multiple coastal areas. In addition, the COVID19 pandemic has limited the opportunities for close collaboration with and involvement of local stakeholders and partners in some MALs, resulting in delayed model development and quantification processes.

Overall, the translation from CLDs to fully quantified SD models has been more complex, and effort, resource and time demanding for the MALs than anticipated (Viaene et al., 2020), posing new challenges for the project progress (Notebaert and De Kok, 2018 – updated in 2020). The SD modelling and its quantification as well as further testing and validation will continue in all MALs at least until the project month 36 (April 2021) and the operational SD sub-models at that time will be reported with updates on their quantification in COASTAL Deliverable D14 of WP4.

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Table 2. Overview of SD sub-model development and quantification status for the MALs. Modified and updated table based on Table 11 in Viaene et al. (2020).

MAL	SD sub-model quantification			
	Planned	Fully quantified	Partially quantified	Not yet quantified
MAL1	2	0	2	0
MAL2	3	0	1	2
MAL3	2	2	0	0
MAL4	4	3	1	0
MAL5	6	0	2	4
MAL6	7	0	7	0
COASTAL (total)	24	5	13	6

Overall, the SD modelling in the different MALs aims to develop a better understanding of the interaction dynamics of coastal and rural systems that can trigger effective sustainable changes. Developed SD models should be useful in supporting identification and testing of local and regional potential for sustainable development (as part of WP3 activities) and guiding transitions to a desirable future (as envisioned by MAL stakeholders and expressed in the first multi-actor workshops that constitute part of the WP5 activities). For this, various types of local/regional development/change scenarios, as listed in Table 3, are considered for testing by the quantified SD models in the different MALs. Such scenarios may address implications of socio-economic, technological, policy, climate and environmental developments and associated uncertainties of relevance for key land-sea interactions in the different MALs, and these should be addressed in the modelling. Table 3 summarizes potential relations of the considered MAL-specific scenario analyses to some key overarching policy frameworks, including the European Green Deal[4] (EC, 2020; according to topics in Figure 9), the United Nations (UN) sustainable development goals (SDGs) in Agenda 2030[5] (UN, 2015; Figure 10), the shared socioeconomic pathways (SSPs) of global climate change scenarios (Riahi et al., 2017; Figure 11), and marine spatial plans (MSP), if/as currently applicable for each MAL based on EU (2014).

Overall, considered scenario analysis in the MALs focuses on specific aspects of the main problems/topics in focus for the SD modelling (depending on model structures and parameter setting as well as data availability). Water quality and associated sectoral contributions/impacts are at the heart of scenario analysis considered in most of the MALs. Moreover, green and blue growth, sustainable tourism activities, ecosystem services, education and training, and innovative sectoral (i.e. agricultural) practices are also considered as MAL-specific scenario analysis scopes. The considered scenario analyses in the different MALs are mostly related to: the two European Green Deal topics "Protecting nature and biodiversity" and "From farm to fork and healthy food system", and the two SDGs 6 (Clean water and sanitation) and 13 (Climate action). Most considered scenario analyses can also, from a broad perspective, be linked to some SSPs, for example through their relations to climate, sustainability and land-use change scenarios in the SPPs. Except for MAL6 – the Spanish case, scenario analysis in other MALs may also be able to address some topics under related MSPs at regional scales. This information on the potential scenario analysis in the different MALs and their possible relation to the key policy frameworks is summarized here in Table 3, based on more detailed outlines in associated tables within each MAL section (see section 5). These outlines, and further SD model

[4] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
[5] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

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development and quantification in the MALs, should be useful in supporting WP3 and WP5 tasks on development of regional business roadmaps, policy guidelines and transition pathways.

Table 3. Summary of the types of scenarios that may be testable/tested through the SD modelling for different MALs, and how these relate to main topics/scenarios of the listed overarching frameworks (European Green Deal topics, Figure 9; SDGs: UN Sustainable Development Goals, Figure 10; SSPs: Shared Socioeconomic Pathways of global change, Figure 11; Topics in MSP: Marine Spatial Plan - if/as applicable in each MAL case).

MAL	Types of scenarios that can/are to be addressed by MAL's SD modelling	Relation to overarching frameworks and their topics/scenarios			
		European Green Deal Topics	SDGs	SSP scenarios	Topics in MSPs
MAL1	Blue growth; Climate resilience	Climate neutrality by 2050; Circular economy; Fair, healthy and environmentally-friendly food system; Preserving and restoring ecosystems and biodiversity	SDGs 6, 7, 9, 12, 13, 15	Sustainability: Taking the green road (SSP1); Middle of the road (SSP2); Inequality: A road divided (SSP4); Fossil-fuel development: Taking the highway (SSP5)	Commissioning of areas allocated to renewable energy production and multiple use of space; Spatial planning and allocation of land use for nature vs. agriculture
MAL2	Hydro-climatic change impacts on water availability and quality; Agricultural practices; Tourism development; National and international environmental regulations and agreements	Protecting Nature; Eliminating Pollution; From Farm to Fork	SDGs 6, 7, 8, 9, 11, 12, 13, 14, 15, 17	Any scenario through relations to RCP-climate scenario, agriculture, land use, GDP, food production and collaborative practices, and technological solutions	Establishment of diving tourism sites and marinas
MAL3	Hydro-climatic change impacts on water availability and quality; Agricultural, urbanization and associated tourism developments; National and international environmental regulations and agreements	Protecting Nature; Eliminating Pollution; Climate Pact/Law; From Farm to Fork	SDGs 6, 11, 13, 14, 15	Any SSP scenario through relations to RCP-climate scenario, and/or land-use, GDP, urbanization, and population evolutions	Swedish Baltic Sea plan – Reinforcement of ecosystem services
MAL4	Development of organic farming (up to 30%) within the hinterland; Decrease of intensive irrigated farming and increase in environmental friendly practices; Maintenance of extensive livestock breeding and associated grasslands on the coastal zone; Development of sustainable coastal and rural tourism; Collective improved water management in the hinterland; Development of agricultural supply chains for export	Form Farm to Fork; Marine Strategy Framework Directive; Common Agricultural Policy; Integrated maritime policy	SDGs 6, 9, 12, 14	Sustainability: Taking the green road (SSP1)	Coexistence of uses; Land-sea interactions; Protect marine environment and preserve marine biodiversity; Coastal tourism

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MAL5	Increasing organic farming and biodiversity-rich landscape features on agricultural land; Reducing the use and harmfulness of pesticides, restoring the Danube river and Danube Delta to a free-flowing state; Planting forest belts; Reducing nutrient losses with no deterioration on soil fertility and reduce of fertilizer use; Investment in education, training and research coupled with increasing seawater temperature effect on the marine aquaculture stock (climate change)	Biodiversity; From farm to fork	SDGs 6, 12, 13, 14	Any SSP scenario related to sustainability, population, and education	MARSPLAN
MAL6	Water pumping from the aquifer to extract pollutants and provide additional irrigation water; Limitation in the number of groundwater wells; Implementation of NBS related to agricultural areas; Promotion of environmental education; Government control on sectorial growth (participatory governance); Decrease in the application of fertilizers; Implementation of brine denitrification technologies; Effect of the implementation of solar photovoltaic facilities in job availability; Effect on water availability of a decrease in water transfer from Tagus-Segura transfer (climate change); 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	Protecting Nature; Eliminating Pollution; Nature-based solutions (NBS); From Farm to Fork; Climate Pact/Law	SDGs 6, 11, 13, 14, 15	Any SSP scenario through relations to RCP-climate scenario, technological development, land-use	No

Figure 9. Main topic structure of the European Green Deal.

Figure 10. The 17 UN Sustainable Development Goals of Agenda 2030.

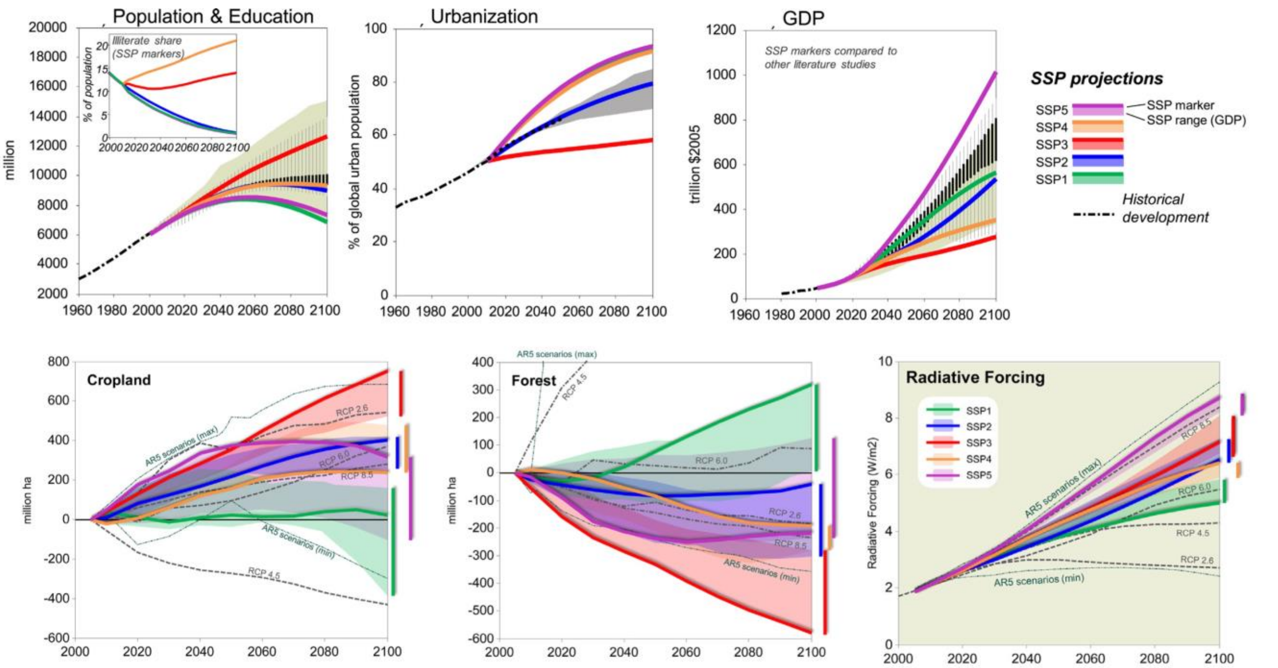

Figure 11. Examples of how the Shared Socioeconomic Pathway (SSP) scenarios of global change relate to global evolution scenarios for different variables; the examples are from Riahi et al. (2017), who provide further variable scenarios related to the SSPs. The different SSPs represent (Riahi et al., 2017): SSP1 - Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation), where the world shifts gradually, but pervasively, toward a more sustainable path; SSP2 - Middle of the Road (Medium challenges to mitigation and adaptation), where the world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns; SSP3 - Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation), where a resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues; SSP4 - Inequality – A Road Divided (Low challenges to mitigation, high challenges to adaptation), where highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries; SSP5 - Fossil-fueled Development – Taking the Highway (High challenges to mitigation, low challenges to adaptation), where the world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development.

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5. MULTI-ACTOR LABS (MALS)

5.1 Multi-Actor Lab 1. Belgian Coastal Zone (North Sea) - Belgium

5.1.1 Introduction and problem scope for land-sea SD modelling

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 12). A new Maritime Spatial Plan (MSP) for the Belgian Coastal Zone for the period 2020-2026 was recently approved[6]. Figure 12 shows the dense use of space and complexity of combining offshore environmental and economic functions.

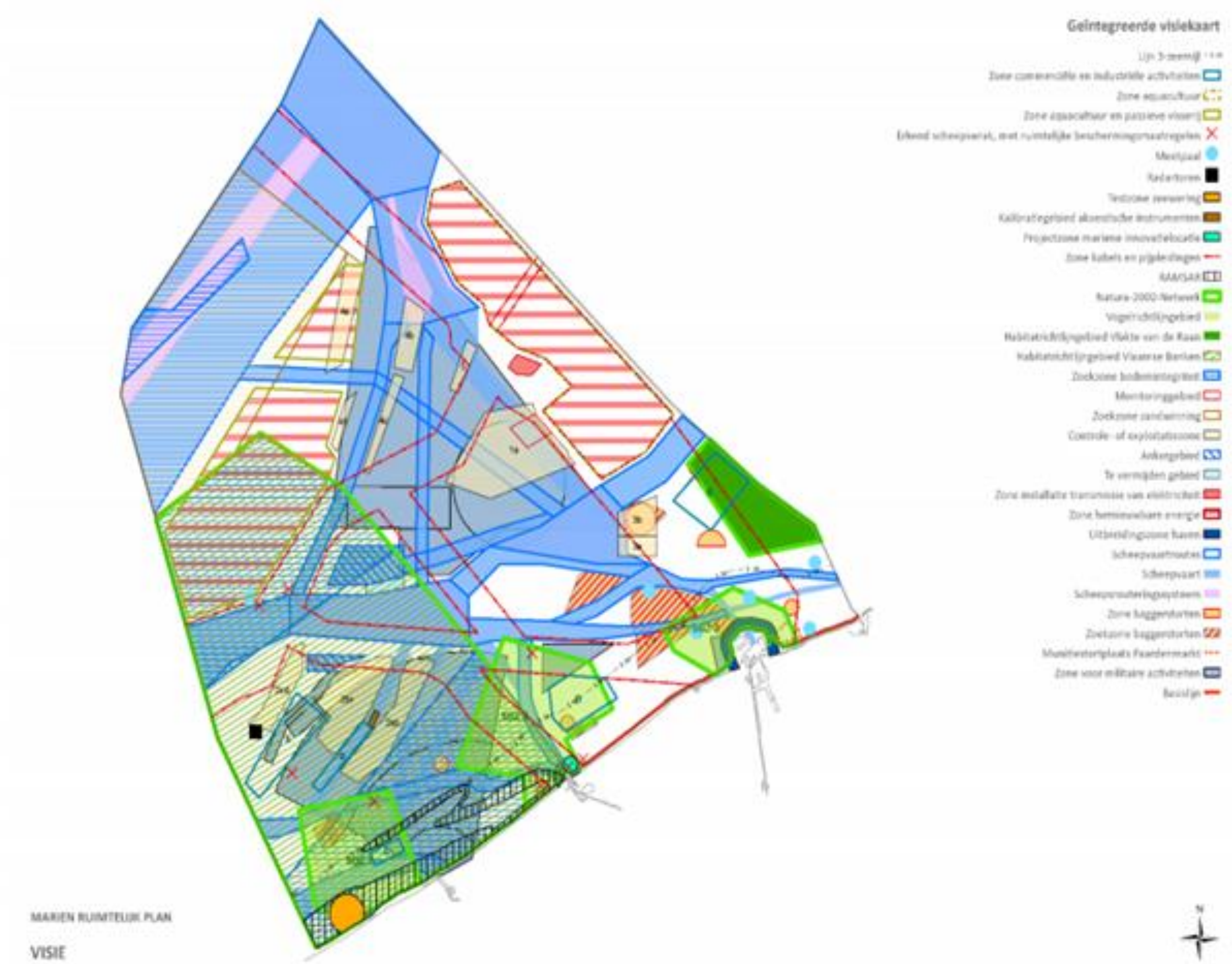

Figure 12. Integrated map as part of the new Marine Spatial Plan 2020-2026 for the Belgian Coastal Zone (Belgian Federal Public Service Health, Food Chain Service and Environment, 2019) (Viaene et al., 2020).

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

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Compared to the other MALs the Belgian MAL is characterized by a broad problem scope with problems and opportunities ranging from water management, inland and marine spatial planning, food transition, tourism and nature restoration to renewable energy development. During the first phase of the project the stakeholder workshops were organized around six “sectors” (Tiller et al., 2019a): environment/nature, spatial planning, agriculture, tourism, fisheries and aquaculture, and finally blue industry. These themes were holistically combined in the first multi-actor workshop (Tiller et al., 2019b). Figure 13 shows a high-level causal diagram of the main interactions between sectors, as identified during the sector workshops and multi-actor workshop, including land-sea interactions which are primarily economic.

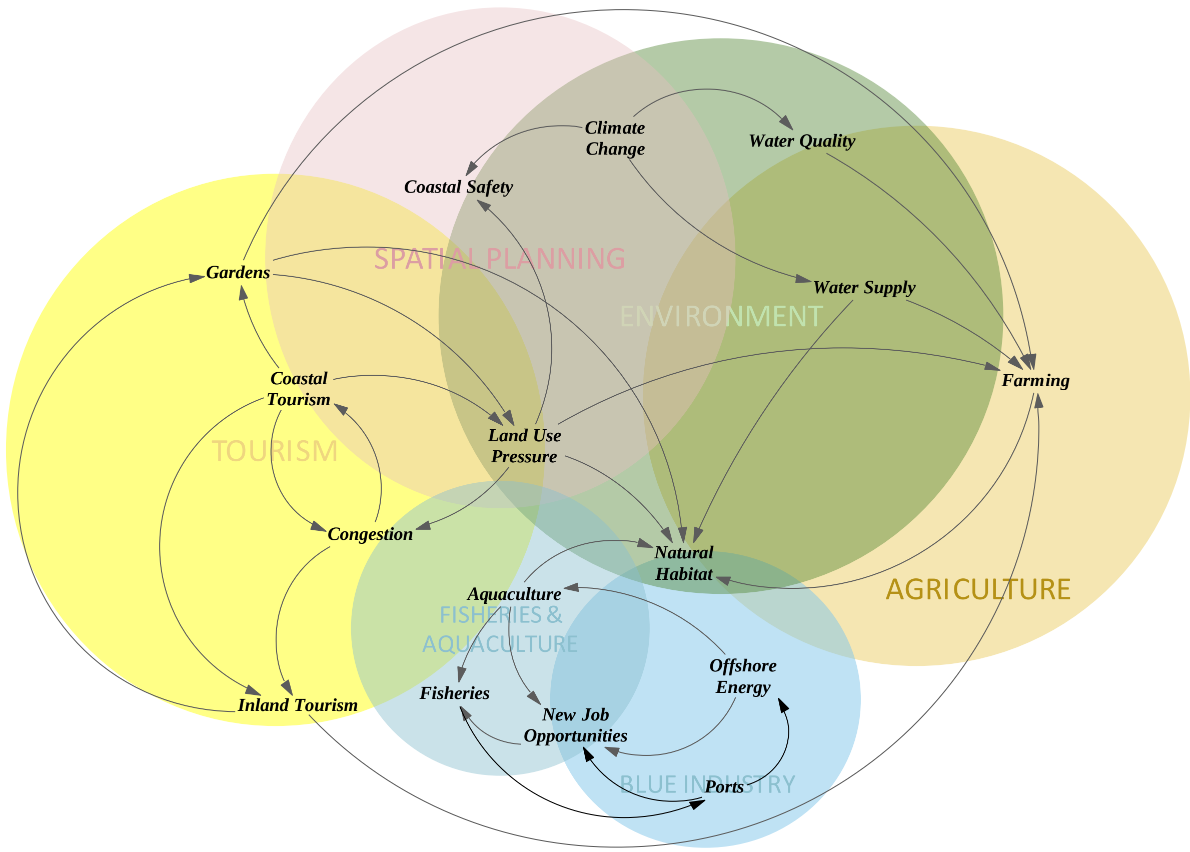

Figure 13. Overview of mind map with the main issues and linkages for the Belgian Multi-Actor Lab (project team analysis), showing the themes for the six sector workshops and overlap in issues raised.

In view of the broad problem scope these interactions were prioritized around three modelling themes related to socio-economic development of the region and climate adaptation (Viaene et al., 2020):

- **Climate resilience**: Impact of sea level rise and other effects of climate change on low lying inland farming land and nature and coastal safety;
- **Ports and renewable energy**: off shore energy production, storage and distribution coupled to employment and onshore infrastructure, including the decommissioning of aged wind parks;
- **Spatial and social transition**: Impact of spatial planning, gentrifcation of farming land, demographic change and tourism development or transformation.

Figure 14 shows the final, polished causal loop diagram (CLD) resulting from the first multi-actor workshop for MAL1 (Tiller et al., 2019b).

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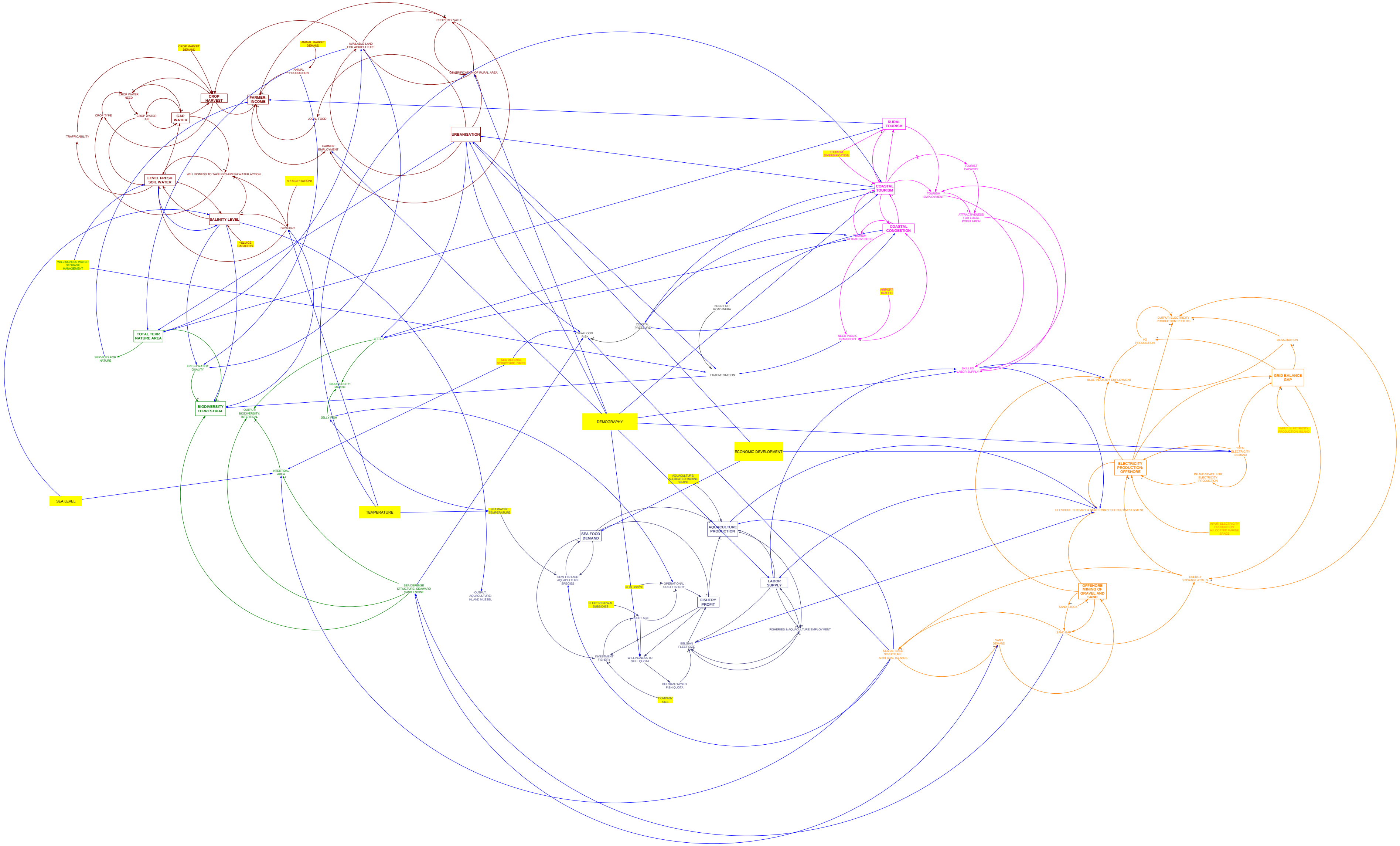

Figure 14. Overall CLD for MAL1 as reported for work package (WP) 4 in COASTAL Deliverable D3 the suggested stock variables are in boxes.

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Together, the large number of variables and interactions the CLD are not favourable for a one-on-one conversion into a stock-flow (SF) model due to the high data demands and mathematical complexity. The CLD should be considered a visualization of the systems as a whole, as perceived by the stakeholders and experts involved in its development. Rather than modelling a system as a whole, SF models should address problems albeit from a holistic perspective (Sterman, 2001). Attempts to model systems as a whole in the past have seldom lead to useful models. This challenge was discussed with the actor partners involved in the project and it was decided to start from two themes which had in common: a central role in the CLD, a high priority in terms of climate adaptation and the European Green Deal (EC, 2020), a high policy and business relevance for the region, and finally a clear presence of economic and/or environmental land-sea interactions:

- **Climate resilience and polder management:** recently the Oudland Polder was subject to a new administrative agreement ('raamakkoord') to manage problems of water management and land use in a systemic way. Hydrological modelling and a new water balance will contribute to understanding the underlying physics but should be integrated with the social and economic processes in a holistic manner. The Oudland polder case has a strong spatial dimension, both at the local level and the level of interacting water compartments. Therefore, the VITO land use change model (RuimteModel) is invoked to include land-use change projections with a high level of spatial detail (1 ha).
- **Port and offshore activities**: to meet the climate adaptation goal of full carbon neutrality by the year 2050 Belgium is making considerable investment in developing offshore wind energy. Activities are focus around the port of Ostend and additional wind parks have been commissioned in the new Marine Spatial Plan for the years 2020-2026. Port infrastructure, services and labor will need to be organized to meet the demands related to the commissioning, maintenance and decommissioning of aged wind parks, the first ones of which were installed in the year 2009. A holistic system model is needed to understand the economic land-sea interactions, and potential and obstacles of offshore wind energy for regional development at the mid- and long-term.

5.1.2 Quantified SD sub-models

For MAL1, two SD sub-models have currently been developed, for which the problems that are addressed by and their current status are presented in Table 4.

Table 4. List of developed SD sub-models, their associated problems and their quantification status (fully/partially/not yet quantified) in MAL1.

No.	Title of SD sub-model	Addressed problems	Status of quantification
1	Climate resilience and polder management	Water management and allocation, spatial planning and the combination of different types of land use (nature, agriculture, residential).	Partially quantified: pilot models for water management and changes in agricultural land-use, land-use scenarios
2	Port and offshore activities	Development of offshore renewable energy and infrastructural demands of decommissioning of offshore wind parks.	Partially quantified: pilot models available for energy production, decommissioning and H2 generation. Holistic model will include services, employment and infrastructural aspects.

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5.1.2.1 Sub-model 1. Climate resilience and polder management

5.1.2.1.1 Quantified key land-sea interactions and feedback structures in sub-model 1

A generalized SF feedback structure was developed and discussed with VLM, the Coastal actor partner involved in the spatial planning for the polder (Figure 15).

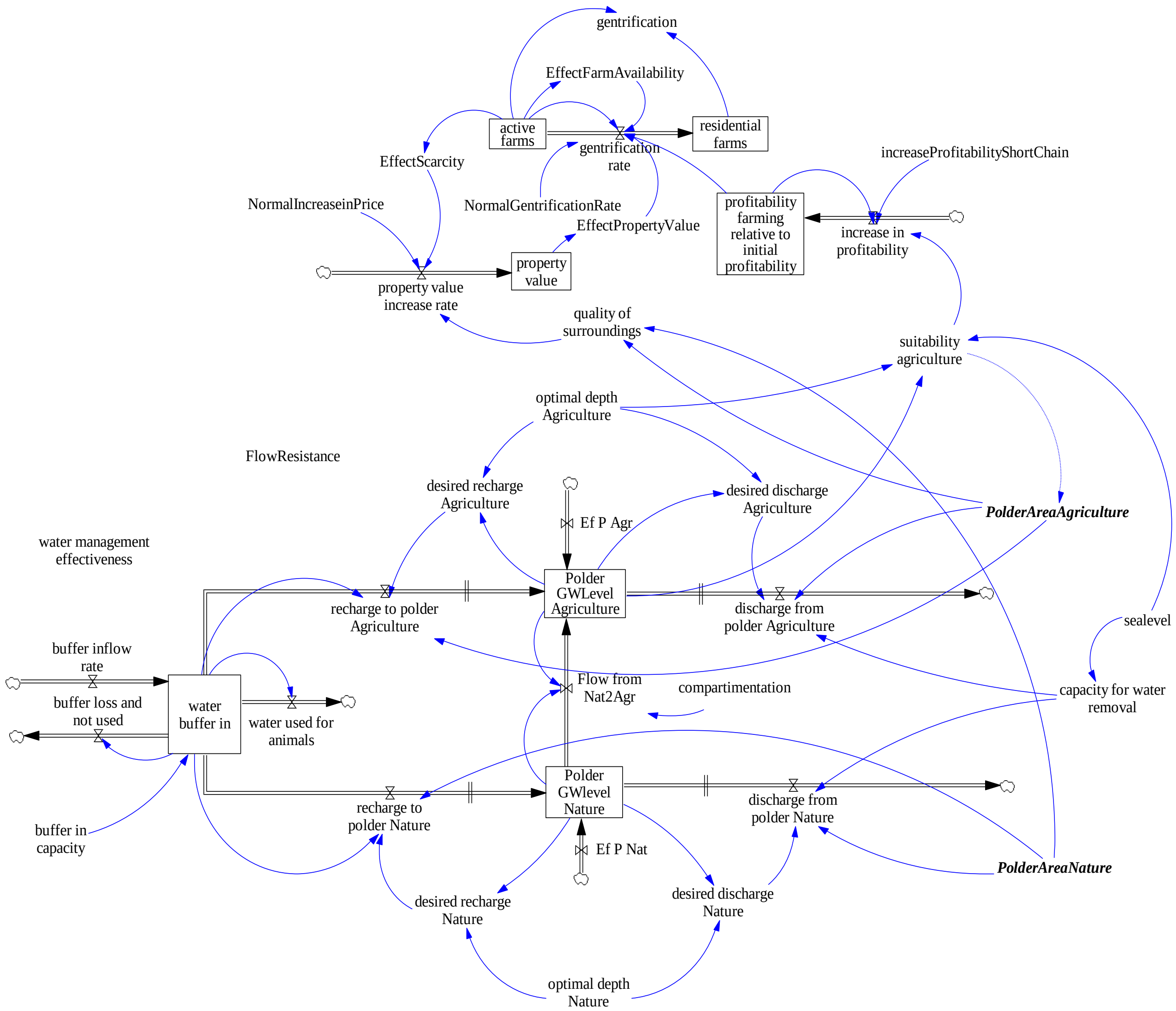

Figure 15. SF structure of SD sub-model 1 in MAL1 developed in Vensim software.

The System Dynamics (SD) model structure was initiated as a simple water balance model for the polder involving a groundwater level that is determined by the input and output of water required to attain a desired groundwater level in accordance with the water management practice. Based on discussions with VLM, this was then extended with the option to investigate the effect of having different land-use and their corresponding water management schemes for agriculture and nature side by side. This was realized by forking the structure into an agriculture and a nature part that are connected through a flow that can be set according to the degree of compartmentation. Besides the water management, the focus in the model is on the disappearance of traditional farming in the polder where some of the farms are bought by the wealthy to become residences, a process we have coined 'gentrification'. In this process, the farm land that goes with the farm is often sold off or loses its agricultural function to become a pasture for the horses or a garden. While the mechanisms underlying the hydrology in the polder are quite well defined, the gentrification process is more difficult to quantify and dimensionless sensitivity functions for different variables identified are used to this end. The water management and gentrification sub-models are interconnected through the land-use.

Initial variables in sub-model 1 were summarized in COASTAL Deliverable D13 – Section 3.1.7 (Viaene et al., 2020) are also presented here in Table 5 with possibly some updates based on the sub-model progress in MAL1.

Table 5. Main variables in SD sub-model 1 for MAL1 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Polder GW Level Agriculture /Nature	m	O	S	The ground water level for the polder in the area assigned to agriculture/nature
Compartmentation	-	I	C	Parameter that determines to what extent the areas assigned to nature and agriculture are hydrologically separated. A value of 1 signifies that no water is exchanged between these areas while zero effectively means that the areas behave as one area.
Water buffer in	m3	O	S	Water buffer for water supplied to the polder
Buffer in capacity	m	L	C	Water buffering capacity for water supplied to the polder
Buffer Inflow Rate	m3/month	I	F	Inflow to the polder from different sources (canal, rainfall recovery, …)
Buffer loss and not used	m3/month	O	F	Part of the Buffer inflow rate that can't be stored in the water buffer in and is not used as recharge to the polder
Recharge to polder Agriculture/Nature	m/month	O	F	Actual water flow to the polder area assigned to Agriculture/Nature
discharge from polder Agriculture/Nature	m/month	O	F	Actual water flow from the polder area occupied by agriculture/Nature
Capacity for water removal	m/month	L	F	Water that can be removed from the polder (gravitational discharge, pumping)
Water used for farm animals	m3/month	O	F	Polder water used in agriculture for animals (cattle, poultry, …)
Specific Yield	m/m	I	C	The amount of water released with change in groundwater level
Flow resistance	month	I	C	Hydraulic resistance to exchange between the groundwater and the ditches in the polder, dependent on topology of the ditches and soil characteristics
Optimal depth Agriculture/Nature	m	I	C	Optimal groundwater level according to the water management scheme for agriculture/nature
Difference Desired depth Agr/Nat	m	O	A	Difference between the actual ground water level in the area occupied by

				agriculture/nature and the level that is optimal for agriculture/nature
Desired recharge Agriculture/Nature	m/month	O	A	Recharge needed to the area occupied by agriculture/nature to reduce the difference between the desired and actual groundwater level in those areas
Desired discharge Agriculture/Nature	m/month	O	A	Discharge needed from the area occupied by agriculture/nature to reduce the difference between the desired and actual groundwater level in those areas
Water Management effectiveness	-	I	C	Degree (0-1) to which the actual water management practice conforms to the desired discharge and recharge.
Precipitation	m/month	I/D	F	Natural surface recharge to the polder area
Evapotranspiration	m/month	I/D	F	Natural surface discharge from the polder area due to crop water uptake and evaporation
Sea level	m	I/L	C	Average monthly sea level
Active farms	#farm	O	S	Farms actively being used for agriculture
Residential Farms	#farm	O	S	Farms that are no longer used for agriculture but as residences
Gentrification rate	#farm/month	O	F	Rate at which active farms are converted to residential farms
NormalGentrificationRate	#farm/month	I	C	Rate at which active farms are under current conditions being converted to residential farms
EffectFarmAvailability	-	O	Lu	Relative change in gentrification rate due to the availability of active farms that can still be converted
Gentrification	-	O	A	Fraction of farms that are residential farms
Property value	Euro	O	S	Average price of a farm
NormalIncreasePrice	Euro/Month	I	C	Farm price increase under current conditions
EffectScarcity	-	O	Lu	Relative change in price due to the availability of active farms that can still be converted
EffectPropertyValue	-	O	Lu	Relative change in gentrification rate due to the value of the active farms that can still be converted
Profitability farming relative to initial profitability	-	O	S	Relative profitability of farming compared to initial profitability
Increase in profitability	1/Month	O	F	Increase in relative profitability
IncreaseProfitability ShortChain	1/Month	I	C	Increase in relative profitability due to direct, local sale of produce on the farm
QualityOf Surroundings	-	O	Lu	Quality indicator for the surroundings that affect the price that is paid for farm to be converted to residences. Depends on presence of agriculture (-) /nature (+)

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SuitabilityAgriculture	-	O	Lu	Indicator for the effect of the polder groundwater level and sea level on the profitability of farming in the polder
PolderAreaAgriculture	m2	I	C	Surface area of the polder used for agriculture
PolderAreaNature	m2	I	C	Surface area of the polder used for nature

5.1.2.1.2 Outline of quantitative information to support sub-model 1

The polder sub-model addresses:

- Water management in the polder taking into account available means of adding or removing water to arrive at a hydrological state that to the extent possible is optimal for various land-uses in the polder considering that there is both agriculture and nature in the polder;
- Changes in farm practices and the disappearance of traditional small scale farming due to their conversion by the wealthy of farms to residential estates a process in which part of the farm land also ends up to be used for leisure or as nature or is sold off to larger agriculture enterprises.

These two sub-topics are interlinked through the land-use component. As SD modelling is less suited for spatial modelling, the land-use modelling is based on the 'Ruimtemodel Vlaanderen'[7]. The 'Ruimtemodel Vlaanderen' model (Engelen et al., 2011) uses cellular automata to predict future land-use changes (White and Engelen, 1997). Cellular automata models have the advantage of being spatially explicit and process-based and allow for the efficient calculation of high spatial resolution maps as required for planning purposes.

Water management part of this sub-model is presented by the following set of equations:

$$PolderLevel_{\frac{Ag}{N}} = \int Recharge_{\frac{Ag}{N}} - Discharge_{\frac{Ag}{N}} + Flow_{Nat2Agr} + EffectivePrecipitation_{\frac{Ag}{N}}\ dt\ \ [\mathrm{m}] \tag{1}$$

$$Recharge_{\frac{Ag}{N}} = Min\left(fMan * DesiredRecharge_{\frac{Ag}{N}} + Discharge_{\frac{Ag}{N}}, \frac{waterbuffer\ in}{dt * PolderArea_{\frac{Ag}{N}}} * fraction_{\frac{Ag}{N}}\right) [\mathrm{m/month}] \tag{2}$$

$$Discharge_{\frac{Ag}{N}} = Min\left(fMan * DesiredDischarge_{\frac{Ag}{N}}, WaterRemovalCapacity * fraction_{\frac{Ag}{N}}\ [\mathrm{m/month}]\right. \tag{3}$$

$$EffectivePrecipitation_{Ag/N} = Precipitation - ET_{Ag/N}\ \ [\mathrm{m/month}] \tag{4}$$

$$DesiredRecharge_{\frac{Ag}{N}} = \max\left(\frac{-difference\ DesiredDepth_{\frac{Ag}{N}}}{dt} - EffectivePrecipitation_{\frac{Ag}{N}}, 0\right) [\mathrm{m/month}] \tag{5}$$

$$DesiredDischarge_{\frac{Ag}{N}} = \max\left(\frac{difference\ DesiredDepth_{\frac{Ag}{N}}}{dt} + EffectivePrecipitation_{\frac{Ag}{N}}, 0\right) [\mathrm{m/month}] \tag{6}$$

$$water\ buffer\ in = \int (buffer\ inflow\ rate - buffer\ loss\ and\ not\ used - recharge_{Ag} * polderArea_{Ag} - recharge_{N} * polderArea_{N} - waterAnimals)\ dt\ \ [\mathrm{m3}] \tag{7}$$

$$WaterRemovalCapacity = GravitationalDischarge + PumpingCapacity\ \ [\mathrm{m3/s}] \tag{8}$$

$$fraction_{Ag/N} = \frac{PolderArea_{Ag/N}}{PolderArea}\ \ [-] \tag{9}$$

$$difference\ DesiredDepth_{\frac{Ag}{N}} = \left(topo - level_{\frac{Ag}{N}}\right) - optimalDepth_{\frac{Ag}{N}}\ \ [\mathrm{m}] \tag{10}$$

[7] https://ruimtemodel.vlaanderen

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$$buffer\ inflow\ rate = \sum water\ source \quad [\text{m3/month}] \tag{11}$$

$$buffer\ loss\ and\ not\ used = MAX\left(0, water\ buffer\ in - buffer\ in\ capacity * PolderArea - \left[recharge_{Ag} * polderArea_{Ag} + recharge_N * polderArea_N + waterAnimals\right] * dt\right) / dt \quad [\text{m3/month}] \tag{12}$$

where, $fMan$ is water management effectiveness (ideally 1 so that water supplied/removed matches the desired quantity [-]), dt is time step [month], $level_{Ag/N}$ is groundwater level [m], $topo$ is topographical height [m], $optimalDepth_{Ag/N}$ is optimal depth of the groundwater table for agriculture (Ag) or nature (N), $Precipitation$ is precipitation [m/month], $ET_{Ag/N}$ is evapotranspiration in the area used for agriculture (A) or nature (N) [m/month], $PolderArea_{Ag/N}$ is polder area assigned to agriculture (Ag) or nature (N) [m2], $water\ source$ is sources of water that can be used to supply water to the polder (canal, waste water treatment plant, etc.) [m3/month], $waterAnimals$ is polder water used for animal husbandry in the polder [m3/month], $buffer\ in\ capacity$ is amount of water that can be stored and used later on to fulfil water needs, $GravitationalDischarge$ is water that can be removed by natural discharge to the sea [m3/month], and $PumpingCapacity$ is water that can be removed by pumping [m3/month].

Water exchanges between the polder and the surrounding area is assumed to be distributed between the agricultural area and nature according to the relative weight of the areas occupied by each of these land use ($fraction_{Ag/N}$). This concept can easily be augmented or replaced with a factor to account for alternative water management assignment rules that distribute available water to either of the two land-use fractions regardless of the area occupied.

For the coastal area a recent water balance study (Antea, 2018) proved to very useful providing numbers for most of the water balance components that can be distinguished such as the water sources that can be used to supply water to the polder that are considered are the canal and the discharge from the waste water treatment plant and precipitation recovered from sealed surfaces. The amount of water needed each month for animals in agriculture was calculated from the statistics on number of cattle, poultry and pigs[8] and the amount of water needed per animal[9].

Information for appropriate ground water depths for agriculture or nature ($optimalDepth_{Ag/N}$) was found in literature (WES, 2005; Integraal Waterbeleid Bekken van de Brugsepolders, 2010). To lower the water level in the polder, water is discharged to the sea. This requires that the polder water level is higher than the sea level. Based on the observed tidal movements at Ostend (Afdeling Kust - Vlaamse Hydrografie, 2016), the station closest to our area of interest the fraction of time for which the sea level is below the polder water level was determined (Figure 16). As sea level rises the time window for discharging water to the sea becomes smaller and smaller and eventually might not be big enough.

[8] https://www.statistiekvlaanderen.be/nl/veestapel

[9] https://www.vmm.be/water/heffingen/bereken-je-heffing/berekening-voor-landbouw

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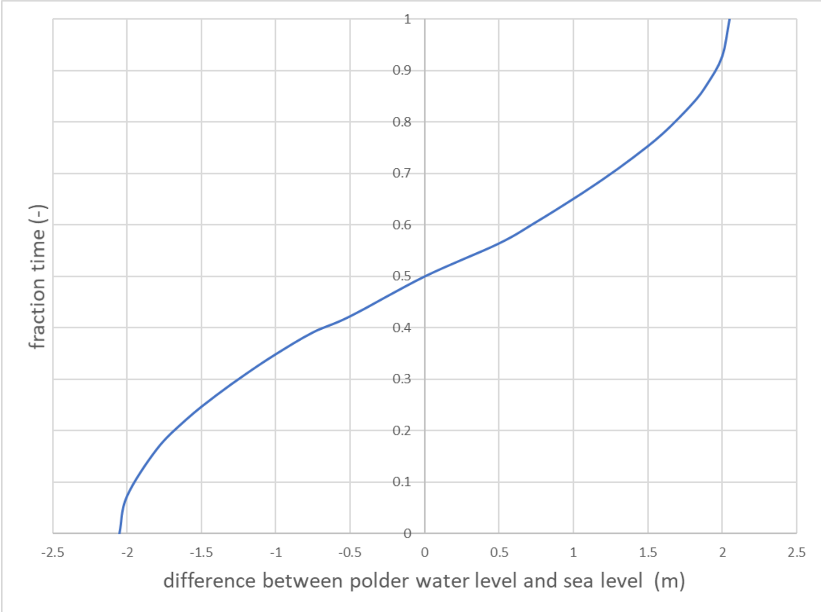

Figure 16. fraction of the available time in a month the sea level is above the polder water level in Ostend for different values of the difference between these two levels.

Besides water management, sub-model 1 also considers the changes to farming in the polder where the classical, smaller family farms are slowly disappearing as they are bought by wealthy people as residences. The following equations are used to describe this process:

$$Active\ farms = \int -gentrification\ rate.dt \quad [\#\ \text{farm}] \tag{13}$$

$$Residential\ farms = \int gentrification\ rate.dt \quad [\#\ \text{farm}] \tag{14}$$

$$\begin{aligned} gentrification\ rate \\ &= (NormalGentrificationRate * Active\ farms * EffectFarmAvailability \\ &* EffectPropertyValue/profitability\ farming\ relative\ to\ initial\ profitability) \\ &* \ Active\ farms/InitialNumberofActiveFarms \quad [\#\ \text{farm/Month}] \end{aligned} \tag{15}$$

$$Property\ value = \int property\ value\ increase\ \ rate.dt \quad [\text{Euro}] \tag{16}$$

$$\begin{aligned} property\ value\ increase\ \ rate \\ &= NormalIncreasePrice * \ quality\ of\ surroundings * EffectScarcity \\ &* property\ value \quad [\text{Euro/month}] \end{aligned} \tag{17}$$

$$profitability\ farming\ relative\ to\ initial\ profitability = \int increase\ in\ profitability\ \ dt \quad [-] \tag{18}$$

$$\begin{aligned} increase\ in\ profitability \\ &= \left(1 + \frac{increaseProfitabilityShortChain}{profitability\ farming\ relative\ to\ initial\ profitability}\right) \\ &* suitability\ agriculture - 1 \end{aligned} \tag{19}$$

where, $EffectFarmAvailability$ is a look-up table for the change in gentrification rate as the number of active farms changes compared to the initial number of active farms, $quality\ of\ surroundings$ is a look-up table for the change in the property value increase rate dependent on PolderAreaNature/InitialPolderAreaNature [-], $EffectScarcity$ is a look-up table for the change in the property value increase rate dependent on the active farms/InitialNumberofActiveFarms [-],

$NormalIncreasePrice$ is the initial property price increase rate set to a 'normal' inflation value = 0.02/12 [1/month], $increaseProfitabilityShortChain$ is fractional change in profitability due to short chain or other profitability enhancing measures given the current profitability [-], and $suitability\ agriculture$ is a look-up table for the change in the property value increase rate depending on the actual groundwater level and the required optimal ground water level [-] (deviations from the optimal value will decrease profitability of farms dependent on crops). The variable $increase\ in\ profitability$ is calculated where the solution is smoothed to account for the delay in excess of the monthly time step.

Currently, future development for different time variant inputs such as animal stock is not considered yet but will be accounted for in concertation with WP3 and WP5 to take into account future pathways envisioned in these work packages for MAL1.

5.1.2.2 Sub-model 2. Port and offshore activities

5.1.2.2.1 Quantified key land-sea interactions and feedback structures in sub-model 2

A generalized SF feedback structure was developed (Figure 17) and discussed with the local partner GRBR and coastal actor partners (POM, AGHO and VLIZ) as blueprint for the model design and implementation.

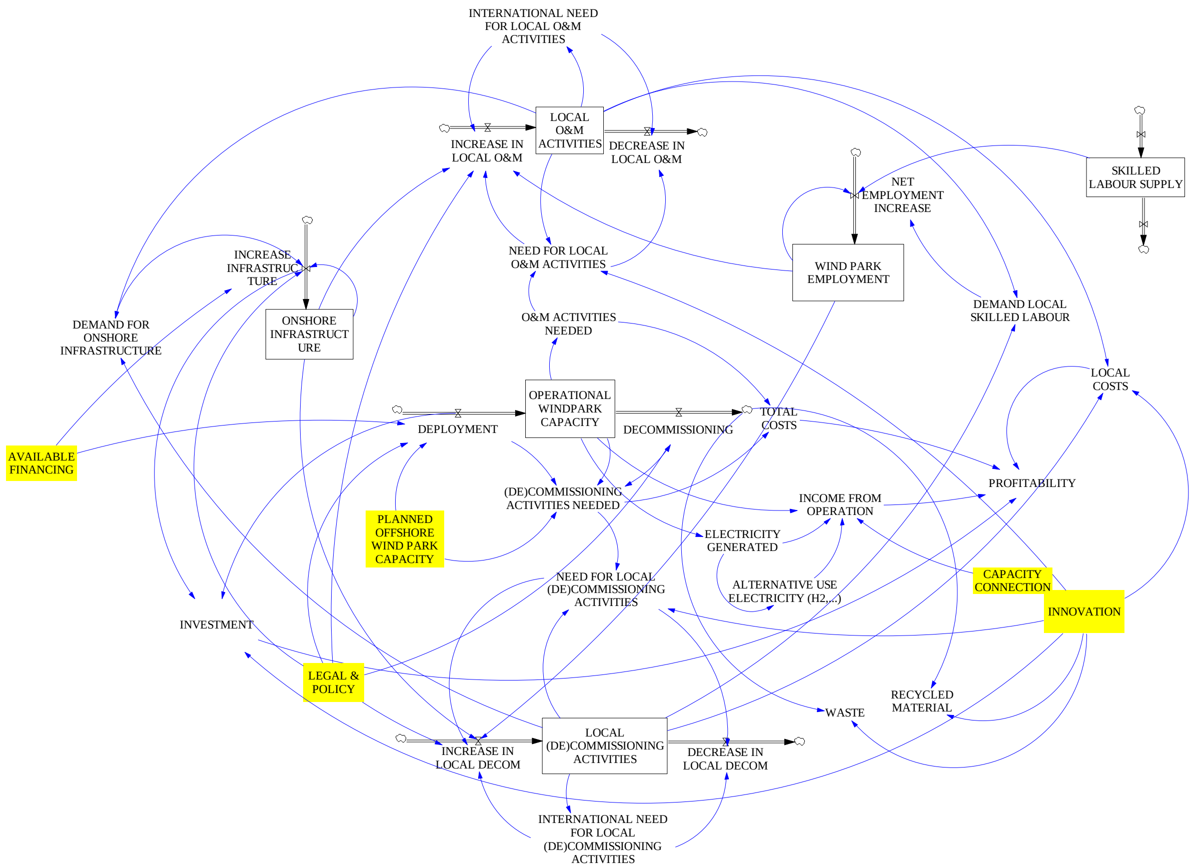

Figure 17. SF structure of SD sub-model 2 in MAL1 (investments, innovation and legal framework related to offshore wind energy in the Belgian North Sea) developed in Vensim software.

It was decided to develop, test and fine tune the SF model step-by-step, starting from the commissioning and decommissioning of wind parks as model cores. Financial, legal-administrative and technological aspects

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may be included in the model in an indirect way, for example by control parameters which can be adjusted to set scenarios. A very important strategic indicator provided by the model will be the decommissioning rate, i.e. the number of wind mills decommissioned – taking into consideration their age and maintenance costs. In case variables or limiting conditions such as infrastructure are difficult to quantify in terms of measurable units, these could be defined as a comparative, dimensionless, indices (100 = initial value). Variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.1.7 (Viaene et al., 2020) and are also presented here in Table 6 with possibly some updates based on the sub-model progress in MAL1.

Table 6. Main variables in SD sub-model 2 for MAL1 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Wind park size / capacity	Wind mills	O	S	Size of the wind parks and age distribution for combined wind parks in the BNS, taking into consideration the commissioning year and decommissioning as a function of wind park life time, which may be variable.
Offshore wind power	MW	O	S	Total power generated for actual wind parks, taking into consideration the impact of age on operational efficiency
Costs of maintenance	EUR per year	O	A	Maintenance costs taking into consideration the age of the wind park.
Decommissioning rate	Number of wind mills per year	O	A	Number of wind mills decommissioned per year, taking into consideration age and maintenance costs.
Maintenance costs	% of LCOE (Leveled Cost Of Energy)	O	Lu	Maintenance costs as a function of park age.
Employment	FTE	O	A	Total direct and indirect employment generated by (de)commissioning, maintenance and services related to offshore wind energy.
Infrastructure	Index compared to initial level (proposal)	L	Lu	Infrastructural requirements for (de)commissioning, maintenance and services. Look-up function as a function of the scale of activities.
Services	Index compared to initial level (proposal)	O	Lu	Services required for (de)commissioning, maintenance and services. Look-up function as a function of the scale of activities.

5.1.2.2.2 Outline of quantitative information to support sub-model 2

The model core is based on the principle of co-aging cohorts, similar as used in demographic projections. The model runs with a time step of one year. Model input is read from an external file (spreadsheet) and includes the number of new wind mills commissioned (installed) for each year in the simulation. At the time of commissioning the new mills will be included in the first age class. For each time step these wind mills will move up one age class until the life time age is reached and the wind mills are decommissioned. Decommissioning may also be triggered by other limiting factors such as the operational costs, the operational efficiency or costs of maintenance. The underlying equation is:

$$N_{i,t+1} = N_{i-1,t} - N_{i,t} \qquad if\ i < T\ then\ N_{T,T+1} = 0 \qquad (20)$$

where, N is the number of wind mills, i refers to the age class with age i, and t is the time step (year), and T is the life time for decommissioning. Non-linear look-up functions will be used for functional relationships in the model, for example for the increase of the maintenance costs as a function of the park age.

Data requirements for the quantification can be categorized as follows:

- Data for initialization of the model (initial number of wind mills, power generated, operational costs, etc.);
- Control data read for each time step (the number of commissioned wind mills, the power per wind mill, etc.);
- Expert knowledge on the shape of the look-up functions;
- Model-specific constants such as the number of jobs generated in maintenance per MWhr.

The majority of these data are already available online through the Belgian Offshore Platform[10], Wind Europe[11] and the 4C Marine Consultants Platform[12].

5.1.3 Synthetic reflection on the quantification process for the different SD sub-models

The general strategy for the development of the overall SD model for MAL1 will be to design and implement the model step-by-step and integrating additional detail only when needed and based on feedback of the actor partners involved in the model design. This is always a good strategy when developing SF models and was discussed and agreed on. The starting point will be a simple pilot model which can address the (de)commissioning of the wind parks and provide projections on the decommissioning rate (number of wind mills decommissioned per year) as this is a key factor for the operational planning, port infrastructure, personnel and services needed. Furthermore, the SF model will be using a spreadsheet with time series for commissioning per year, the power per wind mill, and life time. The SF model should handle the ageing process although this could also be done in the spreadsheet. This will increase the transparency of the model. A strategic choice for the model design concerns the commissioning of new wind parks. In an early version of the model this commissioning was **internalized**, implying that the model automatically allocated new offshore wind parks depending on the availability of marine space. This internalization is appealing as it is easily implemented in a SF model and naturally follows the principles of SD. However, following a discussion of the model with the actor partners it was decided that internalization of this stock (the number of new wind mills in a certain year) was not a good practice, the main reason being that the commissioning is completely based on licensing to companies as a part of the MSP for the Belgian Coastal Zone. Therefore, it was decided to import the year-by-year commissioning and initial power generation from an external data file and let the SF model handle the ageing, interaction with other variables and holistic analysis of the problem case.

[10] https://www.belgianoffshoreplatform.be/nl/projecten
[11] https://windeurope.org
[12] https://www.4coffschore.com/offshorewind

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5.1.4 Plan for scenario analysis using the SD sub-models

As for all MALs, scenarios in MAL1 address socio-economic, technological and environmental (climatological) uncertainties affecting the land-sea system from the outside, as well as policy decisions taken outside the system boundaries (Table 7). The shared socioeconomic pathways (SSPs) function as the basic framework for developing these scenarios. They are complemented, when applicable, with regional and national scenarios, for instance spatial planning scenarios developed by the Flemish government. For the sub-model 1, scenarios focus on the implications of climate change and socio-economic development on land-use change, agriculture, nature restoration and water management. For the sub-model 2, scenarios focus on the relation between decommissioning and the installation of new wind turbines, on the one hand, and employment, industrial port development, development of renewable energy infrastructures, nuclear and fossil-fuel phase-out and the restoration of marine ecosystems on the other hand.

Table 7. Types of scenarios that may be testable/tested through the SD modelling in MAL1 and their relations to topics/scenarios in the listed overarching frameworks (European Green Deal topics, Figure 9; SDGs: UN Sustainable Development Goals in Agenda 2030, Figure 10; SSPs: Shared Socioeconomic Pathways, Figure 11; Topics in applicable MSP: Marine Spatial Plan).

Types of scenarios for SD modelling	Indicate if the scenarios can be related to any of the overarching frameworks and briefly to which framework topics/scenarios			
	Topic in European Green Deal	SDGs	SSP scenarios	Topic in MSP
Climate resilience	Yes Climate neutrality by 2050, Fair, healthy and environmentally-friendly food system, Preserving and restoring ecosystems and biodiversity	Yes SDGs 6, 12, 13, 15	Yes Sustainability: Taking the green road (SSP1), Middle of the road (SSP2), Inequality: A road divided (SSP4), Fossil-fuel development: Taking the highway (SSP5)	Yes Spatial planning and allocation of land use for nature vs. agriculture
Blue Growth	Yes Climate neutrality by 2050, Circular economy[13]	Yes SDGs 7, 9, 13	Yes Sustainability: Taking the green road (SSP1), Middle of the road (SSP2), Inequality: A road divided (SSP4), Fossil-fuel development: Taking the highway (SSP5)	Yes Commissioning of areas allocated to renewable energy production, multiple use of space

5.1.5 Data/Model sources and general references

Sub-model 1 in MAL1:

1. Afdeling Kust - Vlaamse Hydrografie (2016). Overzicht van de tijwaarnemingen langs de Belgische kust, Periode 2001-2010 voor Nieuwpoort, Oostende en Zeebrugge. Vlaamse overheid, Agentschap voor Maritieme Dienstverlening en Kust: Brussel. 41 pp (in Dutch: Overview of tide observations along the Belgian coast, Period 2001-2010 for Nieuwpoort, Ostend and Zeebrugge)
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3. Crols, T. (2017). Integrating network distances into an activity based cellular automata land use model. Semi-automated calibration and application to Flanders, Belgium. PhD dissertation, Vrije Universiteit Brussel & VITO. Brussels: VUBPRESS. http://users.skynet.be/crols/PhD_thesis_Tomas_Crols.pdf

[13] https://ec.europa.eu/commission/presscorner/detail/en/fs_20_40

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Sub-model 2 in MAL1:

14. 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.
15. Bekkenbestuur (2010). Handleiding voor de opmaak van peilbesluiten in de kustpolders. Available at: https://www.integraalwaterbeleid.be/nl/bekkens/bekken-brugse-polders/gebiedsgerichte-werking/handleiding-peilbesluiten/Handleiding%20peilafspraken.pdf/view
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Online available data for sub-model 2 in MAL1:

34. https://www.belgianoffshoreplatform.be/nl/projecten/ (wind park commissioning year, distance to coast, power generated, surface area, number of turbines)
35. https://windeurope.org/data-and-analysis/interactive-data/
36. https://www.4coffshore.com/offshorewind/ (interactive map)

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

5.2 Multi-Actor Lab 2. South West Messina (Eastern Mediterranean Region) - Greece

5.2.1 Introduction and problem scope for land-sea SD modelling

South-West (SW) Messinia is largely an agricultural area with many scattered villages and one coastal town with 2,345 permanent inhabitants (ELSTAT, 2011), whereas the total population of the two municipalities that form the study area in MAL2 is 10,329 (ELSTAT, 2011). Agriculture and tourism are the primary occupations of the local population. Although it is a relatively small area, it includes three Natura 2000[14] sites, as Gialova Lagoon and Sfaktiria Island (GR2550008); a greater area including the coastal sand dunes and the Navarino Bay area (GR2550004); and the more recently established Marine Natura 2000 site of South Messinia (GR2550010) for its importance for cetacean species, since at least four live in the area. Figure 18 shows a general overview of the region.

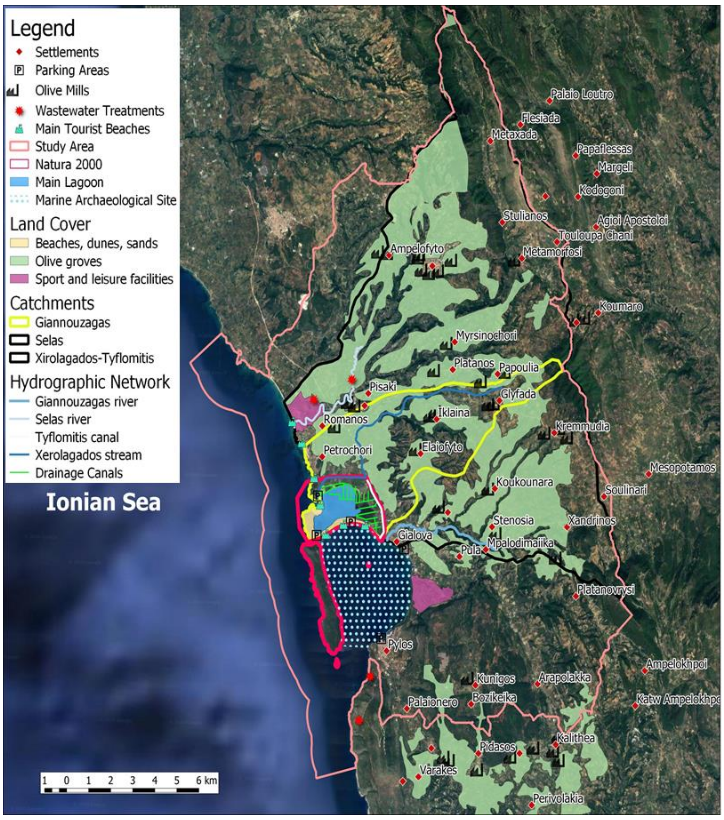

Figure 18. MAL2 case study area (Viaene et al., 2020).

The System Dynamics (SD) models created for the MAL2 of SW Messinia were chosen to relate to the common vision agreed by our stakeholders of "*a Sustainable Messinia, expanding across all sectoral practices and ensuring collaboration among them*" (Tiller et al., 2019b) and address the challenges faced to achieve this vision, as:

- Manage the increasing and seasonal water demand;

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[14] https://ec.europa.eu/environment/nature/natura2000/index_en.htm

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- Improve the ecosystem status of Gialova Lagoon whilst maintaining a viable fishing activity;
- Reduce the use of pesticides/fertilizers in olive groves in compliance with the European Green Deal;
- Expand touristic season and manage the numbers of beach goers in the high season;
- Plan for climate change including potential sea level rise and increased dry spells;
- Reduce the bulk sales of olive oil;
- Manage the pressures for land-use changes in order to maintain the *Identity* of the area; and
- Identify opportunities for farmers and fishers to better connect with the tourism industry.

5.2.2 Quantified SD sub-models

A key issue connecting most of the abovementioned challenges is water supply and demand in particular during the summer months when demand increases exponentially and supply is mainly covered by groundwater reservoirs. This condition is highly unsustainable, and pressures are expected to rise as effects of climate change, affecting social, economic and environmental conditions in the area. Three SD sub-models have been planned and designed to face these challenges, briefly outlined and described in Table 8.

Table 8. List of developed SD sub-models, their associated problems and their quantification status (fully/partially/not yet quantified) in MAL2.

No.	Title of SD sub-model	Addressed problems	Status of quantification
1	Freshwater availability for Gialova Lagoon	• Improve the ecological status of Gialova Lagoon • Improve viability of lagoon fishing activities • Address climate change effects on the lagoon ecosystem	Partially quantified
2	Integrated farming	• Water demand for irrigation in agriculture • Reduce the use of pesticides/ fertilizers in olive groves in compliance with the European Green Deal • Plan for climate change in farming sector • Reduce bulk sales in olive oil • Identify opportunities to connect farmers with tourism sector	Not yet quantified
3	Sustainable tourism	• Water demand in tourism sector and household supply • Manage the numbers of beach goers in high season • Pressures on landscape character brand name • Alternative tourism opportunities through connection with nature-based activities	Not yet quantified

Of these planned sub-models, the MAL2 research team has decided to start the quantification process by addressing the Freshwater availability for Gialova Lagoon, the first sub-model, which is described in greater detail in the following associated sections. The other two sub-models have been redesigned since COASTAL Deliverable D13 for WP4, hence their quantification is still in progress. The main reason for this decision was based on recent discussions with the actor partners within MAL2. As an outcome of these discussions, it was decided to redefine some of the challenges related to sub-models 2 and 3. In addition, both of these sub-models had a high degree of complexity which needed to be simplified to make the models meaningful for stakeholder interactions and policy making.

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The main stock variable of SD sub-model 2 is the size of land (in hectares) under integrated farming, which is an intermediate step between organic and conventional agriculture and local partners wish to see it being addressed within the next 10 years, also in compliance with the European Green Deal policies. Such a change is connected with a reduction in groundwater abstraction as well as a reduction in the use of fertilizers and pesticides. Nitrogen fertilization inputs in intensively farmed olive groves range from 150-350 kg/ha, whereas in integrated olive groves it is around 75 kg/ha (Pienkowski and Beaufoy, 2002). Number of farmers adopting integrated practices leads to an increase in the stock variable, whereas a possible return to conventional practices due to dissatisfaction with the outcomes of the integrated practices leads to a decrease in the stock variable. Some of the factors driving farmers' willingness to change their practices are: (i) organization of farmers into cooperatives with the provision of economic incentives and high quality services; (ii) clear guidance of new farming methods; (iii) increase of employment and marketing potential (olive oil market and price); (iv) change in operation standards with modernization of olive mills, etc. Similarly, a decrease rate of Integrated Farming Land (stock variable) in sub-model 2, is governed by factors mainly related to the actual income of farmers. Such factors can be the increased expenses of olive oil production in integrated farming (more labor, purchase of efficient equipment for irrigation, less productivity per hectares, payment of memberships to farmers' cooperatives), which may be balanced with an increased oil price and subsidies received.

To complete quantification of the sub-model 2 based on relations of the above-mentioned factors with the aggregated 'increase rate' and 'decrease rate' parameters, we still investigate them with respect to their social and environmental effects. The latter also expresses the connection of this sub-model with the other two sub-models for MAL2. Specifically, the extent of Integrated Farming Land (stock variable) (and the remaining conventional area) will result in changes in river pollution due to nitrogen losses, and groundwater availability (connection with the Lagoon sub-model), as well as, to specific levels of terrestrial and coastal ecosystem health which may affect tourism (connection with the Tourism model). The connections to the other sub-models will assist in highlighting land-sea interactions that are not obviously visible only within the sub-model 2. Finally, some modifications can also be considered in the sub-model 2 to better address the connections with the other two sub-models and the general vision for North-West Messinia, for example, the Total Farming Land may be selected to vary over years and/or to include other cultivations apart from the dominant olive trees.

The third sub-model that is still not quantified is the sustainable tourism sub-model which is twofold. On one hand, it deals with the impact of tourism on water demands, and on the other hand, with the branding of the sustainable Messinia, as part of the tourism product on offer to attract destination tourists. As this is highly connected to the sub-model 2, it has been decided that the quantification of this sub-model is addressed once the sub-model 2 is fully quantified and is able to run. However, the effects of the seasonal increase of population due to tourism and as a result the increasing water demand are calculated as part of the sub-model 1, which addresses the salinity and freshwater availability for Gialova Lagoon, as explained in associated sections.

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5.2.2.2 Sub-model 1. Freshwater availability for Gialova Lagoon

5.2.2.2.1 Quantified key land-sea interactions and feedback structures in sub-model 1

At the core of the MAL2 case, lies a coastal wetland, Gialova Lagoon 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[15]). Over 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). Fish management in the wetland is important to sustain fish stocks at sea, but at present survival of commercially important fish species found in the lagoon, is also affected by increased salinity. At present, human water uses for various purposes and sectors depend on groundwater resources, and agricultural practices, demography and tourism affect the amount of available groundwater for the wetland. Under future drier and warmer conditions, salinity in the lagoon is expected to increase even more, unless freshwater inputs are enhanced by restoring hydrologic connectivity between the lagoon and the surrounding freshwater bodies (Manzoni et al., 2019).

Sub-model 1 investigates how inland human water uses affect the groundwater resources of Tyflomitis aquifer, which is the main provider of freshwater inputs to the coastal wetland, and how current conditions create critical conditions for fish (Figure 19). It also investigates the implications of climate change on precipitation, evaporation/evapotranspiration, and subsequently on irrigation, and how these changes may affect groundwater availability. Variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.2.8 (Viaene et al., 2020) and are also presented here in Table 9 with possibly some updates based on the sub-model progress in MAL2. The sub-model will be used during the upcoming multi-actor workshop as part of WP1 to present the current conditions of the lagoon and how these may change under future climate conditions, and to drive the discussions on scenarios of how to increase freshwater inputs to the lagoon.

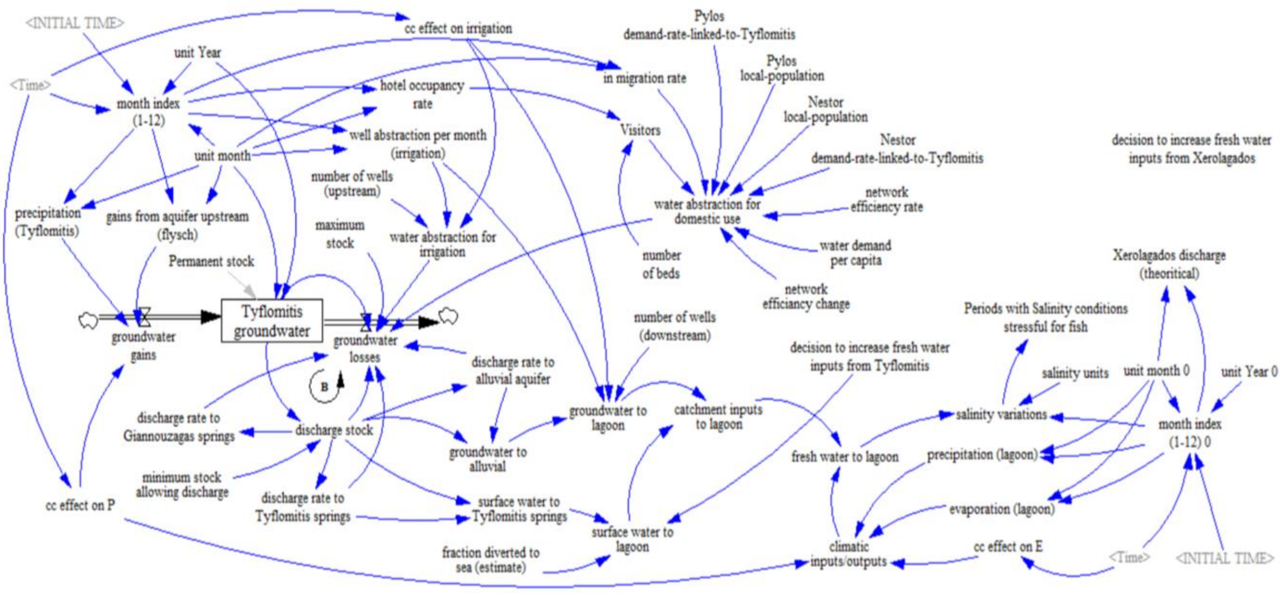

Figure 19. SF structure of SD sub-model 1 in MAL2 developed in Vensim software.

[15] https://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm

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Table 9. Main variables in SD sub-model 1 for MAL2 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Tyflomitis groundwater	m^3	O	S	The groundwater volume at Tyflomitis aquifer
Initial stock	m^3	I	A	The initial stock of the aquifer in January 2020
groundwater gains	m^3/month	I	F	Atmospheric water + groundwater inputs from adjacent aquifer
precipitation (Tyflomitis)	m^3/month	I	Lu	Monthly inputs due to precipitation as a Look-up (seasonality effect)
gains from aquifer upstream (flysch)	m^3/month	I	Lu	Monthly inputs from groundwater aquifer located upstream of Tyflomitis as a Look-up (seasonality effect)
groundwater losses	m^3/month	O	F	Groundwater feeding to adjacent aquifers, natural discharge via springs and groundwater abstraction for irrigation and domestic use
discharge stock	m^3	O	A	Tyflomitis stock that is discharged naturally via springs and to adjacent groundwater aquifers
minimum stock allowing discharge	m^3	B	C	the minimum stock which allows discharge via springs and to adjacent groundwater aquifers
maximum stock	m3	B	C	the maximum stock of Tyflomitis aquifer
discharge rate to alluvial	1/month	O	A	Literature based rate: percentage of Tyflomitis groundwater feeding alluvial aquifer
discharge rate to Giannouzagas	1/month	O	A	Literature based rate: percentage of Tyflomitis groundwater discharged via springs to Giannouzagas catchment
discharge rate to Tyflomytis springs	1/month	O	A	Literature based rate: percentage of Tyflomitis groundwater discharged via Tyflomitis springs
water abstraction for irrigation	m^3/month	O, D	A	Groundwater volume abstracted for irrigation **(input from sub-model 2)**
water abstraction for domestic use	m^3/month	O, D	A	Groundwater volume abstracted for domestic use **(input from sub-model 3)**
groundwater to alluvial (wetland)	m^3/month	O,	A	volume from Tyflomitis aquifer feeding the alluvial aquifer downstream (coastal aquifer under Gialova wetland)
groundwater to lagoon	m^3/month	O,	A	groundwater feeding the Lagoon after water abstraction for irrigation
surface water to Tyflomitis springs	m^3/month	O	A	volume from Tyflomitis aquifer discharged at Tyflomytis springs
fraction diverted to sea (estimate)	Dmnl	B	C	estimate of the amount of water diverted to sea due to man-made constructions
surface water to lagoon	m^3/month	O	A	surface water feeding the Lagoon (what remains after water diversion to sea)
catchment inputs to lagoon	m^3/month	O	A	the sum of groundwater and surface water
Precipitation (lagoon)	m^3/month	I	Lu	Monthly water inputs to lagoon due to precipitation as a Look-up (seasonality effect)

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evaporation (lagoon)	m^3/month	O	Lu	Monthly water outputs from the lagoon due to evaporation as a Look-up (seasonality effect)
P_E	m^3/month	I, O	A	Difference between Precipitation and Evaporation
freshwater to lagoon	m^3/month	B	A	The sum of catchment and P-E
salinity variations	(g/m^3)/month	O	A	salinity variations linked to freshwater inputs
salinity units	$(g/m^3)/m^3$		C	
Period with Salinity conditions stressful for fish		O		period of time with hypersaline conditions (Salinity > 0.0385 g/m^3)
Xerolagados discharge	m^3/month	I	Lu	Monthly discharge at Xerolagados river as a Look-up function (seasonality effect) to be used in scenarios
cc effect on P	Dmnl	L, B	Lu	Look up function adding the effect of climate change to precipitation (values to be validated based on IPCC model predictions) - to be used in scenarios
cc effect on E	Dmnl	L, B	Lu	Look up function adding the effect of climate change to evaporation (values to be validated based on IPCC model predictions) - to be used in scenarios
cc effect on irrigation	Dmnl	L, B	Lu	Look up function adding the effect of climate change to irrigation (values to be validated based on communication with experts) - to be used in scenarios

5.2.2.2.2 Outline of quantitative information to support sub-model 1

Our MAL2 case study contains municipality districts of Pylos and Nestor, with 5,287 and 5,042 inhabitants, respectively, and it is part of the Pylos-Nestor municipality which in total has 21,077 inhabitants (ELSTAT, 2011). Tyflomitis groundwater aquifer, covers an area of around 15,4 km^2 (15,388,006 m^2), and it is part of the Tyflomitis-Xerolagados catchment. It is a small aquifer, but with high importance for the local society, the sensitive ecosystem of Gialova Lagoon and the Navarino Bay coastline. The aquifer consists of conglomerates, which have an infiltration rate of 23% (ENVECO, 2009). The conglomerates continue to spread under the alluvial deposits of Gialova Lagoon (have been met by drills). Due to tectonics, they have been submerged and covered by the alluvial deposits creating conditions of water supply due to pressure difference. It is estimated that the aquifer is divided to smaller sub-aquifers, which can be explained by the presence of several springs at its inner and peripheral areas as Tyflomitis, Elaiofyto, Iklaina, and Koukounara (Figure 20).

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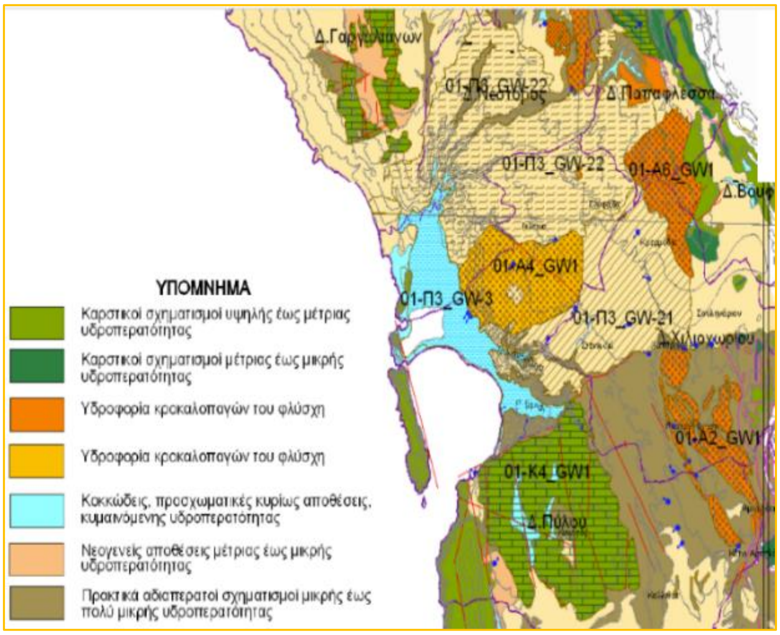

Figure 20. Hydrological map of the area for Tyflomitis aquifer (01-A4_GW1) in MAL2 (found in ENVECO, 2009_A&B).

According to previous studies (ENVECO, 2009), the permanent stock of the aquifer was estimated at 6,5 hm^3, the average buffer stocks at 3,4 hm^3 (3.398.351 m^3), and the maximum buffer stock at 3,42 hm^3 (3,418,172 m^3). The buffer volumes are in practice the available volumes of the aquifer.

Sub-model 1 runs on the time basis of years covering the period 2020-2040, with time steps of 0.08333 which was selected to allow monthly time steps. The initial time will be set at January 2020. Due to high seasonality effects in the system, all inputs (e.g. precipitation, water demand) and outputs (e.g. evaporation) are imported as Lookup functions to allow monthly values (e.g. m^3/month). The following equation is used to introduce seasonality based on time steps:

month index (1-12)" = unit month*(1+MIN(12,MAX(0,INTEGER(MODULO(12*((Time-INITIAL TIME)/unit Year),12))))) (21)

Tyflomitis groundwater is the only stock in the sub-model 1. It is calculated at each time step as:

Tyflomitis groundwater = groundwater gains - groundwater losses (22)

The initial value of our stock, calculated based on Equation (22), will be 6,500,000 + 360,000 m^3. The 6,500,000 m^3 is the permanent stock of the aquifer (ENVECO, 2009). The extra 360,000 m^3 is the extra volume which we estimate that has been available in January 2020, assuming that at the end of October all renewable stocks are used (either abstracted for anthropogenic uses or naturally discharged). At each month, the groundwater gains will be:

groundwater gains = ("precipitation (Tyflomitis)"+"gains from aquifer upstream (flysch)") * cc effect on P (23)

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According to ENVECO (2009), the mean annual precipitation above Tyflomitis is 735 mm/year, but there are no data on monthly values. Navarino Environmental Observatory (NEO)[16] has long-term data series from Methoni station (15.4 km south of Tyflomitis). Based on this data series, we have produced a precipitation factor for each month, that is the percentage of precipitation for each month. The produced factor was multiplied by the average of 735 mm/year to create monthly values. These monthly values were then multiplied by 0.001 to convert mm to m, and then by the area of Tyflomitis (15,388,006 m^2) and the infiltration rate (0.23) to calculate the value of m^3/month that enters the aquifer. The calculations will be made in excel, and the products were added in our sub-model using a lookup function.

According to ENVECO (2009), the mean annual precipitation above Flysch conglomerates is 885 mm/year, and to produce monthly values, we used the precipitation factor introduced above. The produced monthly values were then multiplied by 0.001 to convert mm to m, and then by the area of Flysch conglomerates (6510700 m^2) and the infiltration rate (0.23). 75% of the groundwater is side feeding Tyflomitis conglomerates and the rest of 25% is discharged via springs to Giannouzagas aquifer (ENVECO, 2009), thus, the produced monthly values were multiplied by 0.75. The calculations will be made in excel, and the products were added in our sub-model using a lookup function.

In both lookup functions, when precipitation is below 20 mm/month, the input volume is set at 0. In order to add the effect of climate change in our sub-model (changes in precipitation), we created another lookup function for changes during the period 2020-2040 (values to be validated based on Intergovernmental Panel on Climate Change (IPCC) model predictions).

"precipitation (Tyflomitis)" = WITH LOOKUP ("month index (1-12)"/unit month, ([(0,0)-12,600000)], (1,428827),(2,302683),(3,250523),(4,131518),(5,78909),(6,0),(7,0),(8,0),(9,127688),(10,309026),(11,428206),(12,507202))) (24)

"gains from aquifer upstream (flysch)" = WITH LOOKUP ("month index (1-12)"/unit month, ([(0,0)-(12,200000)],(1,163849),(2,115651),(3,95722),(4,50251),(5,30150),(6,0),(7,0),(8,0),(9,48788),(10,118075),(11,163612),(12,193795))) (25)

cc effect on P = WITH LOOKUP (Time, ([(2020,0)- (2040,2)], (2020,1),(2021,1),(2022,0.95),(2023,0.94),(2024,0.95),(2025,1),(2026,1.1),(2027,1.05),(2028,0.85),(2029,0.87),(2030,0.85),(2031,0.9),(2032,0.75),(2033,0.77),(2034,0.74),(2035,0.8),(2036,1),(2037,1),(2038,1.2),(2039,0.6),(2040,0.65))) (26)

The *groundwater losses* of the aquifer are due to groundwater side outputs to alluvial sediments (01-Π3_GW1) found in the west side (Figure 20) of Tyflomitis conglomerates, discharge via springs and groundwater abstraction for water supply and irrigation (ENVECO, 2009). At each month, the groundwater losses will be:

groundwater losses= (discharge rate to Tyflomitis springs + discharge rate to Giannouzagas springs + discharge rate to alluvial aquifer) * discharge stock * (maximum stock - Tyflomitis groundwater)/ maximum stock + water abstraction for irrigation + water abstraction for domestic use (27)

The maximum stock of the aquifer is 9,900,000 m^3 (ENVECO, 2009). The discharge stock is the buffer stock of Tyflomitis aquifer. This stock is a limiting factor for the natural discharge of the system, but not for the

[16] https://www.navarinoneo.se/

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water abstractions to cover irrigation and domestic use. It is defined as the difference between *Tyflomitis groundwater* and the *minimum stock allowing discharge* which is 6,500,000 m^3 (the same as the permanent stock).

According to ENVECO (2009), on annual basis, 15% of Tyflomitis groundwater is side feeding the alluvial sediments (01-П3_GW1) found in the west side (Figure 20) of Tyflomitis conglomerates. The rest of the groundwater volume is discharged as surface water to springs (15% via a spring to Giannouzagas catchment, and 70% at Tyflomitis springs). Thus, the values of discharge rate to Tyflomitis springs, discharge rate to Giannouzagas springs, and discharge rate to alluvial aquifer are 0.7, 0.15 and 0.15, respectively. These rates were added to the sub-model using the function IF THEN ELSE (e.g. discharge rate to Tyflomitis springs= IF THEN ELSE (discharge stock > 0, 0.7, 0). The water abstraction for irrigation is defined as:

water abstraction for irrigation = "well abstraction per month (irrigation)"*"number of wells (upstream)"*cc effect on irrigation (28)

To estimate *water abstraction for irrigation*, we will rely on the estimates given in ENVECO (2009) coupled with data on wells provided by NEO, in order to get a mean value for *water abstraction per well (irrigation)*. The number of wells above and downstream of Tyflomitis are at least 39 and 24, respectively. In order to add the effect of climate change in our sub-model (cc effect in irrigation), we created a lookup function for changes during the period 2020-2040 (values to be validated based on discussions with experts before and during the second multi-actor workshop as part of WP1).

"well abstraction per month (irrigation)" = WITH LOOKUP ("month index (1-12)"/unit month, ([(0,0)-(12,5000)],(1,0),(2,0),(3,0),(4,129),(5,982),(6,1447),(7,4629),(8,4266),(9,2703),(10,250),(11,0),(12,0))) (29)

cc effect on irrigation = WITH LOOKUP (Time, [(2020,0),(2040,2)],(2020,1),(2021,1),(2022,1.1),(2023,1.1),(2024,1.1),(2025,1),(2026,0.85),(2027,0.9),(2028,1.2),(2029,1.2),(2030,1.2),(2031,1.1),(2032,1.3),(2033,1.3),(2034,1.25),(2035,1.2),(2036,1),(2037,1),(2038,0.8),(2038,0.7),(2039,1.4),(2040,1.3))) (30)

The water abstraction for domestic use is defined as:

water abstraction for domestic use = ((("Pylos local-population"*"Pylos demand-rate-linked-to-Tyflomitis" + "Nestor local-population" * "Nestor demand-rate-linked-to-Tyflomitis") * in migration rate + Visitors * "Pylos demand-rate-linked-to-Tyflomitis")) * water demand per capita * network efficiency rate * network efficiency change (31)

The efficiency of the water supply networks was estimated at 67% (ENVECO, 2009). This will be added in the sub-model as a *network efficiency* rate and will be a constant which equals to 1.49. The *network efficiency change* is currently 1. It will be used to estimate how less the water abstraction could be in the future given improvements of the network under different scenarios to be discussed during the second multi-actor workshop.

The average water demand per capita is estimated at 0.177 m^3 (177 lt) per day[17] or 0.177 * 30 = 5.31 m^3/month. Our MAL2 case study contains the municipality districts of Pylos and Nestor, with 5,287 and 5,042

[17] https://www.statista.com/chart/19591/average-consumption-of-tap-water-per-person-in-the-eu/

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inhabitants, respectively (ELSTAT, 2011). Based on available information (ENVECO, 2009), groundwater from Tyflomitis aquifer is used to cover the water supply needs for 62% of the total population water needs in the Pylos municipality district. Thus *Pylos demand-rate-linked-to-Tyflomitis = 0.62* and *Nestor demand-rate-linked-to-Tyflomitis = 0.09.* The *in-migration rate* is a lookup function which is produced based on empirical data. It is used to introduce the seasonal increase of local population due to secondary houses and labour work demand in tourism and agriculture sectors (values to be validated based on discussions with experts before and during the second multi-actor workshop as part of WP1).

The *visitors* variable is the product of the amount of beds (constant at 1348) with the hotel occupancy rate with the number of 30 (number of days per month). The hotel occupancy rate is a lookup function produced based on empirical data, used to introduce visitors' seasonality (values to be validated based on discussions with experts before and during the second multi-actor workshop as part of WP1).

hotel occupancy rate = WITH LOOKUP ("month index (1-12)"/unit month, ([(0,0)-(12,1)], (1,0.05),(2,0.05),(3,0.1),(4,0.6),(5,0.3),(6,0.5),(7,0.7),(8,0.9),(9,0.5),(10,0.3),(11,0.1),(12,0.1))) (32)

in migration rate = WITH LOOKUP ("month index (1-12)"/unit month, ([(1,0.9)-(12,3)], (1,1),(2,1),(3,1),(4,1.5),(5,1.5),(6,1.7),(7,2),(8,2),(9,1.6),(10,1.3),(11,1),(12,1))) (33)

The catchment inputs to lagoon will be defined as:

catchment inputs to lagoon = groundwater to lagoon + surface water to lagoon (34)

The groundwater to lagoon is the remaining groundwater after water abstraction for irrigation. This variable was added using the IF THEN ELSE function, assuming that only what is left from irrigation is an input to the lagoon.

After major human interventions, most of the *surface water at Tyflomitis springs*, is diverted to sea, and at present (after interventions in 1999-2000) only a fraction of this volume is entering the lagoon (Maneas et al., 2019). We estimate that the *fraction diverted to sea (estimate)* is at present 0.8 (that is 80% of the water discharged at Tyflomitis springs). The *decision to increase freshwater inputs from Tyflomitis* is currently 1. It is added to estimate the increase in water volumes from Tyflomitis after relevant decision making, under different scenarios to be discussed during the second multi-actor workshop.

groundwater to lagoon = IF THEN ELSE (groundwater to alluvial-"well abstraction per month (irrigation)"*"number of wells (downstream)" * cc effect on irrigation >0, groundwater to alluvial -"well abstraction per month (irrigation)" *"number of wells (downstream)" *cc effect on irrigation, 0) (35)

Surface water to lagoon = (1-"fraction diverted to sea (estimate)"/decision to increase freshwater inputs from Tyflomitis) * surface water to Tyflomitis springs (36)

The climatic inputs/outputs is the defined as:

"climatic inputs/outputs" = "precipitation (lagoon)"*cc effect on P-"evaporation (lagoon)"*cc effect on E (37)

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The *lagoon precipitation* and the *lagoon evaporation* are estimated based on historical monthly averages (Maneas et al., 2019), and are converted to m^3/month when multiplied by the lagoon area (2,500,000 m^2). They are inserted in the sub-model as lookup functions. In order to add the effect of climate change in our sub-model (changes in evaporation), we created a lookup function for changes during the period 2020-2040 (values to be validated based on IPCC model predictions). The changes in precipitation are already mentioned above.

cc effect on E = WITH LOOKUP (Time, ([(2020,0.8)-(2040,2)], (2020,1),(2021,1),(2022,1.05),(2023,1.06),(2024,1.05),(2025,1),(2026,0.9),(2027,0.95),(2028,1.15),(2029,1.13),(2030,1.15),(2031,1.1),(2032,1.25),(2033,1.23),(2034,1.26),(2035,1.2),(2036,1),(2037,1),(2038,0.8),(2039,1.4),(2040,1.35))) (38)

"evaporation (lagoon)" = WITH LOOKUP ("month index (1-12) 0"/unit month 0, ([(0,0)-(12,400000)], (1,49678),(2,67420),(3,131196),(4,208600),(5,292562),(6,375022),(7,398005),(8,296176),(9,181299),(10,114883),(11,56291),(12,52029))) (39)

"precipitation (lagoon)" = WITH LOOKUP ("month index (1-12) 0"/unit month 0, ([(0,0)-(12,400000)], (1,286424),(2,202170),(3,167330),(4,87844),(5,52705),(6,13161),(7,2920),(8,8348),(9,85286),(10,106406),(11,286009),(12,338772))) (40)

The freshwater inputs to lagoon will be defined as:

freshwater to lagoon = catchment inputs to lagoon + "climatic inputs/outputs" (41)

The *salinity variations,* is a variable estimated based on two lookup functions which link the *freshwater to lagoon* with the *salinity variations*. Both functions are empirical, but they are validated versus available data[18]. They produce results which are within the expected salinity variations and follow the expected seasonality. The variable *salinity units,* is used to convert m^3/month to (g/m^3)/month.

salinity variations = IF THEN ELSE ("month index (1-12) 0">1: OR: "month index (1-12) 0"<8, -3e-05 *freshwater to lagoon + 36.362, -2e-06*freshwater to lagoon + 22.203) *salinity units (42)

The *discharge at Xerolagados river* is not yet used in the sub-model, but it is part of it as expected to be discussed during the second multi-actor workshop as a tentative solution for increasing freshwater inputs to lagoon. The lookup function is based on data found in ENVECO (2009).

"Xerolagados discharge (theoritical)" = WITH LOOKUP ("month index (1-12) 0"/unit month 0,([(0,0)-(12,2e+06)], (1,993329),(2,883229),(3,504679),(4,216508),(5,106908), (6,31245),(7,7128), (8,6420), (9,32477), (10,133284), (11,637150), (12,1.61927e+06))) (43)

[18] https://bolin.su.se/data/manzoni-2020

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5.2.2.1 Sub-model 2. Integrated farming

5.2.2.1.1 Quantified key land-sea interactions and feedback structures in sub-model 2

The sub-model scope was determined based on the outcomes of the first multi-actor workshop (Tiller et al., 2019b), and our understanding of the system. More sustainable agriculture, needs to build on young generations, exploit technological advances (e.g. smart agriculture) and respond to new requirements (e.g. European Green Deal) with efficient plans. 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. According to our stakeholders, a transition from conventional to organic farming is not a realistic goal (Tiller et al., 2019b), at the moment. Instead they envision a future where there is a transition from conventional to integrated olive farming, and they argued that a more integrated olive farming is the most proper way to sustain olive-oil production in the area up to specific standards (Tiller et al., 2019b). However, in our MAL2 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 (Viaene et al., 2020).

Figure 21 presents the initial design of the SF structure for this sub-model which is still in progress. The preliminary list of main variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.2.8 (Viaene et al., 2020).

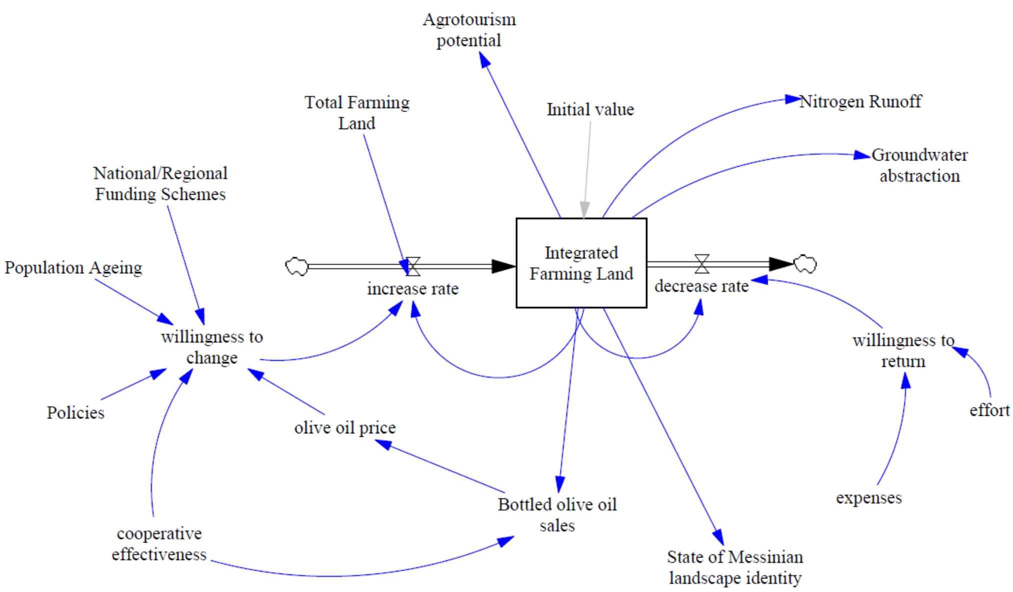

Figure 21. SF structure of SD sub-model 2 in MAL2 developed in Vensim software.

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5.2.2.1.2 Outline of quantitative information to support sub-model 2

This sub-model is not quantified yet. Data inventory, collection and model implementation are still in progress.

5.2.2.3 Sub-model 3. Sustainable tourism

5.2.2.3.1 Quantified key land-sea interactions and feedback structures in sub-model 3

The sub-model scope was determined based on the outcomes of the first multi-actor workshop (Tiller et al., 2019b), and our 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. Tourism is being recognized as a major economic driver for the area and most regional and national development policies also recognize the need and the potential for tourism expansion in Messinia. This potential was discussed by the participants in our multi-actor workshop (Tiller et al., 2019b), 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 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 recognized 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 recognized 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 (Viaene et al., 2020).

Figure 22 presents the initial design of the SF structure for this sub-model which is still in progress. The preliminary list of main variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.2.8 (Viaene et al., 2020).

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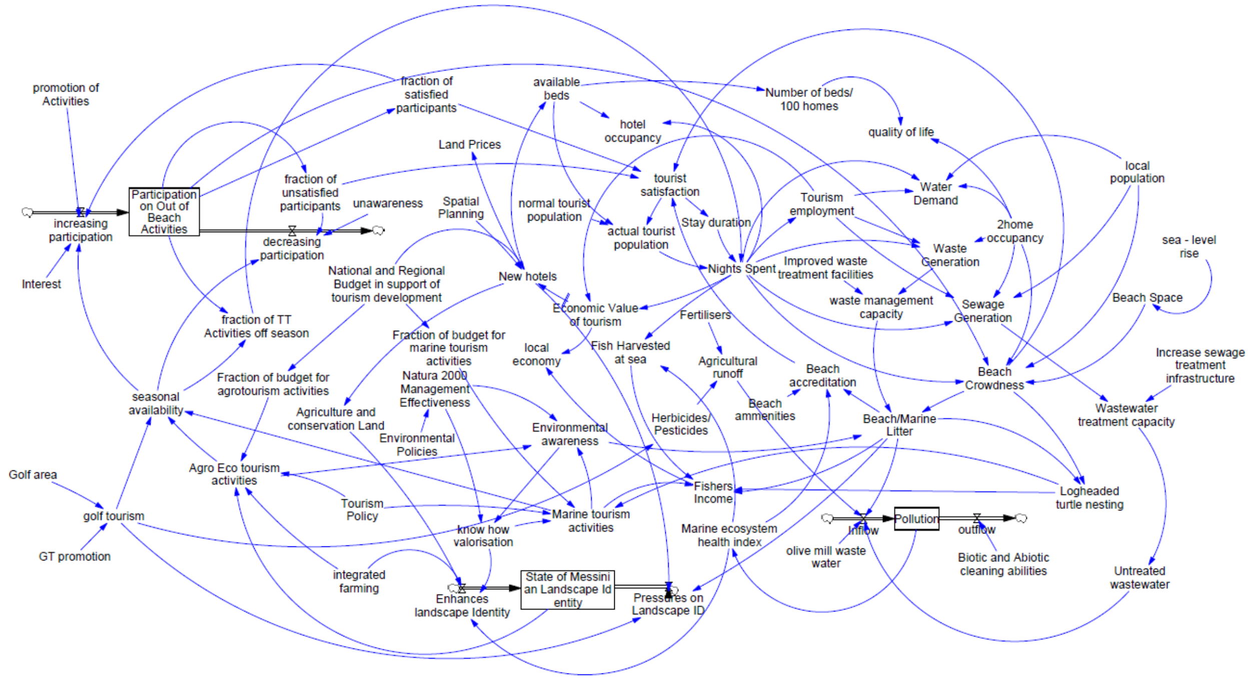

Figure 22. SF structure of SD sub-model 3 in MAL2 developed in Vensim software.

5.2.2.3.2 Outline of quantitative information to support sub-model 3

This sub-model is not quantified yet. Data inventory, collection and model implementation are still in progress.

5.2.3 Synthetic reflection on the quantification process for the different SD sub-models

As only one sub-model has been quantified so far in MAL2, synthesis discussion is based on a descriptive analysis of the connections between the sub-models. A change in the farming practices, is related to both groundwater use and fertilizer input, both of which have an impact on the ecological status of Gialova Lagoon, by increasing nitrogen inflows and reducing the amount of freshwater available to the lagoon. Similarly, the increase in population caused by tourism also reduces freshwater availability to the lagoon during the summer months when salinity reaches critical levels for the fish fauna. At the same time, the willingness to differentiate in the tourism industry by offering a sustainable Messinia brand name requires a good ecological status of the lagoon, a change in the farming practices, in addition to better managing the seasonal influx of people by improving waste and wastewater infrastructures.

5.2.4 Plan for scenario analysis using the SD sub-models

The developed SD sub-models in MAL2 will be used to test various types of local/regional development/change scenarios, as listed in Table 10 and address the scenario implications for land-sea interactions and associated water quantity and quality changes in the region, as well as the viability of the farming and fisheries sectors. In general, scenarios of MAL2 will be associated with water availability and water quality relating to increases in the dry spells, and population mobility and increase of social capital. The expected scenario analysis and its impacts can be related to the key overarching frameworks addressed in Table 10. In terms of National Policies and Laws, expected changes in biodiversity protection and management of the protected areas as well as changes in tourism policy (under public consultation) are also

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expected to highly affect the outcomes of the sub-models. Similarly, the establishment of regional climate adaptation plans that are currently being discussed at a national level, as well as changes in regional development planning for both land and marine areas will also affect the outcomes of scenario analysis.

Table 10. Types of scenarios that may be testable/tested through the SD modelling in MAL2 and their relations to topics/scenarios in the listed overarching frameworks (European Green Deal topics, Figure 9; SDGs: UN Sustainable Development Goals in Agenda 2030, Figure 10; SSPs: Shared Socioeconomic Pathways, Figure 11; Topics in applicable MSP: Marine Spatial Plan).

Types of scenarios for SD modelling	Indicate if the scenarios can be related to any of the overarching frameworks and briefly to which framework topics/scenarios			
	Topic in European Green Deal	SDGs	SSP scenarios	Topic in MSP
Hydro-climatic change and its impacts on water availability and quality	Yes Protecting Nature; Eliminating Pollution	Yes SDGs 6, 13, 14	Yes Any scenario through RCP-climate scenario relations	Yes
Agricultural practices	Yes Protecting Nature; Eliminating Pollution; From Farm to Fork	Yes SDGs 6, 7, 8, 9, 11, 12, 15, 17	Yes All, through connections with agriculture, land use, food production and collaborative practices and technological solutions	Yes
Tourism development	Yes Protecting Nature; Eliminating Pollution	Yes	Yes All, through connections to, land use, and GDP	Yes Establishment of diving tourism sites and marinas
National and international environmental regulations and agreements	Yes Protecting Nature; Eliminating Pollution; From Farm to Fork	Yes SDGs 6, 14, 15	To be determined	To be determined

5.2.5 Data/Model sources and general references

1. ELSTAT (2011). Table B18. Population-Housing Census 2011. Normal houses by residence status.
2. Maneas, G., Makopoulou, E., Bousbouras, D., Berg, H., and Manzoni, S. (2019). Anthropogenic changes in a Mediterranean coastal wetland during the last century-The case of Gialova Lagoon, Messinia, Greece. Water, 11(2), 350.
3. Manzoni, S., Maneas, G., Scaini, A., Berg, H., Destouni, G., and Lyon, S.W. (2019). Closing the hydrologic balance of the Gialova Lagoon, Greece. Geophysical Research Abstracts, 21.
4. Pienkowski M., and Beaufoy G. (2002). The environmental impact of olive oil production in the European Union: practical options for improving the environmental impact. European Forum on Nature Conservation and Pastoralism
5. ENVEKO (2009). Water Resources Management Study for Pylos and Romanos Catchments, Phaces A&B, C, D&E; Technical Report Submitted to the Region of Peloponnese; Enveco S.A.: Athens, Greece, September 2009. (In Greek)

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5.3 Multi-Actor Lab 3. Norrström/Baltic Sea – Sweden

5.3.1 Introduction and problem scope for land-sea SD modelling

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 23). In the Swedish part of the Baltic catchment, the Norrström drainage basin (outlined in Figure 23) and its adjacent and surrounding coastal zones (all together constituting the local MAL3 in COASTAL, and corresponding to the total Swedish Northern Baltic Proper water management district) is a key area with a total population of 2.9 million people. 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 addressed 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 23. The Baltic Sea and its catchment area with the Norrström drainage basin outlined in yellow.

The Norrström drainage basin and associated Swedish Northern Baltic Proper water management district (especially in its eastern parts) are 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

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affecting each other's activities. Coastal tourism development and expansion of summer houses with previous temporary occupation to now increasingly extended up to whole-year occupation increase water supply and wastewater facilities. These were previously typically not connected to municipal water and wastewater utilities, and if such conditions continue, they will cause further inland, coastal and marine water quality issues. If they are to be connected, these coastal house development trends will require expansion of the municipal utilities. Therefore, water quantity and quality and/or their management are significantly affected by these alternative development choices and sectoral interactions in the coastal region. In addition, hydro-climatic changes may affect water quantity availability as well as occurrence and frequency of extreme events such as floods and droughts, with both security and economic implications for regional and local sectoral developments, storm water handling, and wastewater treatment. Shifts in hydro-climate and/or cross-system/sector water interactions further affect both quantity and quality of coastal waters, and associated interactions and needs for (further) costly measures, e.g., for pollution/eutrophication mitigation (Bring et al., 2015a). In addition, coastal water resources are under increasing pressures from human activities in the land catchment (e.g., changes in extent/intensity of agriculture, forestry, industry), resulting in changed risks of seawater intrusion into coastal groundwater, and associated water quantity and quality issues for municipal water supply (MWS) and wastewater treatment plants (WWTP).

Figure 24 illustrates schematically the involvement of various economic sectors, hydro-climate changes, policies and market forces, and their mutual interactions with regard to various water-related problems in MAL3. These interactions are structured with local and regional stakeholders in sector and multi-actor workshop (Tiller et al., 2019a and 2019b) and considered in the MAL3 system dynamics (SD) modelling, to address the associated problems. Using water and its inter-system/sectoral flows as a (change) tracer, the developed SD models in MAL3 support assessment of possible changes in cross-system/sectoral water quantity/availability and quality under different local/regional developments and hydro-climatic changes.

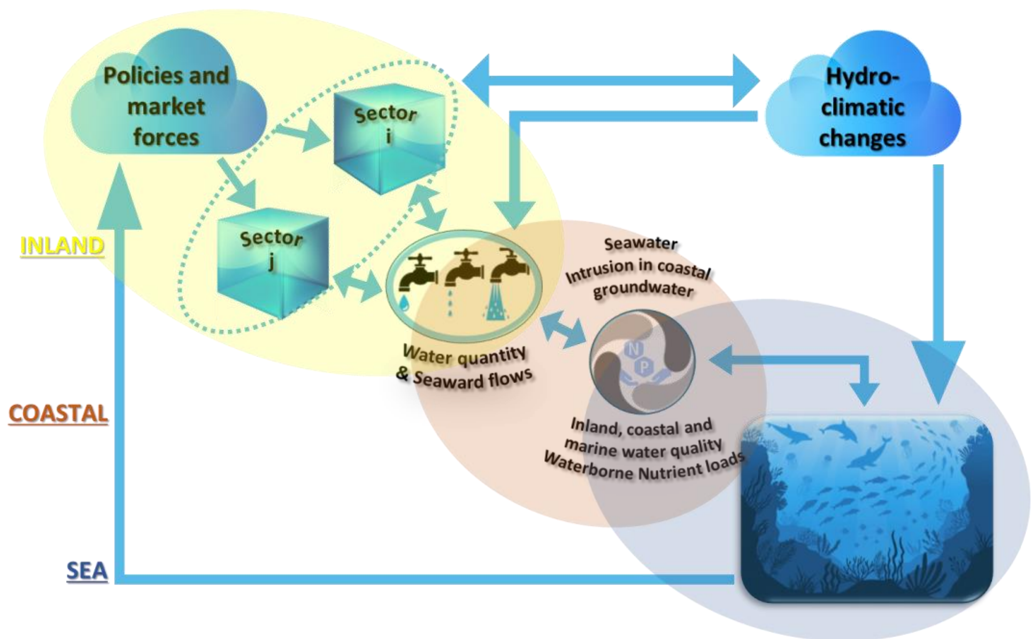

Figure 24. Schematic of physical, socio-economic, and environmental components of water-related problems in MAL3 and their interactions, considered for SD modelling in MAL3.

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5.3.2 Quantified SD sub-models

SD modelling in MAL3 is focused on land-, water- and nutrient/eutrophication-management problems and possible solution pathways that may be driven by policy and/or market forces (as outlined in Table 44 in the updated COASTAL Deliverable D06 - Kastanidi et al., 2018/2020). Considering the data and model (results) availability in MAL3, two main SD sub-models have been developed as listed in Table 11. Various problem aspects that can be investigated in each sub-model are also outlined in this table. Available scientific peer-reviewed published data and modelling approaches along with measured and reported data have supported the full quantification of the two sub-models. Model simulations are mainly based on annual time steps and total simulation period is mostly considered as 100 years, starting from recent-current conditions, considered around year 2010 (Cseh, 2009). The quantification process for these sub-models, along with quantitative data and equations used as support information and models, are explained in detail in the following sections.

Table 11. List of developed SD sub-models, their associated problems and their quantification status (fully/partially/not yet quantified) in MAL3.

No.	Title of SD sub-model	Addressed problems	Status of quantification
1	Land-sea inter-sectoral and coastal water exchange	• Land competition among urban, agriculture and forestry sectors • Water availability for terrestrial ecosystems (through surface and subsurface water flows) • Urban expansion, population and tourism growth, associated water availability and supply issues and storm water handling problems in urban areas • Water availability/waterlogging for agriculture and forestry sectors • Policy implementation and enforcement driving local/regional developments in agriculture, forestry, urban and tourism sectors	Fully quantified
2	Land-sea inter-sectoral and coastal waterborne nutrient exchange	• Land competition among urban, agriculture and forestry sectors • Urban expansion, population and tourism growth, associated water availability and supply issues, storm water handling problems in urban areas, and unconnected coastal wastewater handling concerns • Water availability/waterlogging for agriculture and forestry sectors • Lack of water flow and nutrient monitoring • Active significant contribution of past nutrient legacy sources to inland, coastal and marine waters • Policy implementation and enforcement driving local/regional developments in agriculture, forestry, urban and tourism sectors	Fully quantified

5.3.2.1 Sub-model 1. Land-sea inter-sectoral and coastal water exchange

5.3.2.1.1 Quantified key land-sea interactions and feedback structures in sub-model 1

In the Norrström drainage basin and its adjacent and surrounding Baltic coastal zones, human water uses for various purposes and sectors has increased over the last century, along with population growth in total and in the individual household, agricultural and industrial sectors. The increasing interactions between natural

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water systems and cycling and the different man-made water systems and anthropogenic water impacts commonly imply increasing human water uses of different types, which need to be considered as an integrated part of overall water cycling. The feedback of natural water availability to sectors may also to some degree affect economic development and growth possibilities in the region (Baresel and Destouni, 2005). Coastal groundwater is also part of the total water resource for drinking, food production (coastal agriculture) and economic activities (coastal tourism) in coastal areas. Besides the significant rate of sea level rise, patterns and trends of coastal groundwater extraction directly affect seawater intrusion trends into that groundwater. In addition, hydro-climatic changes and associated alterations of flow/pressure forcing on coastal groundwater from both the land and the marine side can result in significant changes in groundwater level, seaward flow, and seawater intrusion. Such alterations can threaten large-scale contamination of coastal groundwater resources (Mazi et al., 2016).

Sub-model 1 investigates inland sectoral and coastal system interactions with regard to water flux and the risks of water availability through natural surface and subsurface water systems. It also focuses on the implications of the seaward freshwater flows and their possible future changes for seawater intrusion risks in the MAL3 coastal region. Figure 25 shows the overall stock-flow (SF) structure of this sub-model for MAL3. This structure includes urban, agriculture and forestry sectors, natural surface and subsurface waters, water utilities, storm water and WWTP. Ecosystem and urban/coastal tourism are also addressed through various interactions with relevant system components in this sub-model. Sub-model 1 for MAL3 is structured based on the main variables that were listed in COASTAL Deliverable D13 – Section 3.3.7 (Viaene et al., 2020) and are also presented here in Table 12 with possibly some updates based on the sub-model progress in MAL3. In this sub-model, precipitation, land areas for agriculture, urban and forestry sectors are the main input variables while evapotranspiration, cross-system/sectoral water flux exchanges, total coastal water outflow and proxy of seawater intrusion risk are the main output variables.

Table 12. Main variables in SD sub-model 1 for MAL3 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant, SW: surface water, SSW: subsurface water, MWS: municipal water supply, UCWW: unconnected coastal wastewater, USR: urban surface runoff, WWTP: wastewater treatment plant, CCWI: cross-catchment water inflow, CCWE: cross-catchment water export).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Total catchment area	m^2	I, L	A, C	Total or representative inland catchment of considered coastline
SW area	m^2	I, B	A	SW area within catchment
Agricultural land area	m^2	I, B, D	A	Agricultural area within catchment
Forest land area	m^2	I, B, D	A	Forest area within catchment
Built land area	m^2	I, B, D	A	Urban built area within catchment
Other areas	m^2	I, B	A	Land area without buildings, agriculture, forest and water cover within catchment
Precipitation	m/year	I, D	A, C	Long-term average precipitation over catchment
CCWI to SSW	Million m^3/year	I	F	Additional long-term average net groundwater inflow from adjacent basins (CCWI) to the catchment SSW
Precipitation to SW	Million m^3/year	I	F	Annual water input fluxes from precipitation to SW – proportional to relative SW area

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Evapotranspiration	Million m^3/year	O	A	Total annual evapotranspiration
SW to evapotranspiration	Million m^3/year	O	F	Annual water output flux by evaporation from SW – proportional to relative SW area
Flows between natural water systems and inland/coastal sectors	Million m^3/year	O	F	Exchange matrix for annual water flows among SW and SSW as natural water systems, and agriculture, forest, USR, industry, MWS, UCWW and WWTP sectors
Flow fractions between natural water systems and inland/coastal sectors	1/year	I, B	A, C	Factor matrix for annual water flow exchanges among SW and SSW as natural water systems, and agriculture, forest, USR, industry, MWS, UCWW and WWTP sectors
SW	Million m^3	O	S	Total annual SW availability (including also sectoral return flows to SW)
SSW	Million m^3	O	S	Total annual SSW availability (including also sectoral return flows to SSW)
Agriculture	Million m^3	O	S	Total annual water availability for agriculture (including also other sectoral return flows to agriculture)
MWS	Million m^3	O	S	Total annual water availability for MWS
Industry	Million m^3	O	S	Total annual water availability for industry (including also other sectoral return flows to industry)
Total water outflow to coast	Million m^3/year	O	A	Total annual water outflow to the coast
SW outflow to the coast	Million m^3/year	O	F	Annual water flows to the coast through SW and riverine network
SSW outflow to the coast	Million m^3/year	O	F	Annual water flows to the coast through SSW and subsurface flows
MWS to CCWE	Million m^3/year	O	F	Additional long-term average drinking water export from the catchment MWS
Proxy of seawater intrusion risk (SWIR)	Dmnl	O	A	Proxy of seawater intrusion risk for coastal groundwater – related to SSW outflow to coast

5.3.2.1.2 Outline of quantitative information to support sub-model 1

Figure 26 shows a land-use map for the Norrström drainage basin, with an outlet through the Stockholm city to the archipelago and further into the Baltic Sea. Norrström is the catchment of Sweden's third largest lake, Lake Mälaren, and it constitutes the main part of the Northern Baltic water management district, which is one of the five Swedish water districts established for water resource management, according to the European Water Framework Directive (WFD 2000/60/EC European Parliament and the Council of the European Union (EU), 2000). The total area of the Norrström drainage basin is about 22,600 km^2 (Lindgren et al., 2007; Cseh, 2009), divided into 4% built-up (urban) area, 36% agricultural and open land, 49% forest (mostly in the north-west of the basin), 1.5% wetlands and 9.5% inland waters (Cseh, 2009). The total basin area and this division of it are included in simulations with sub-model 1.

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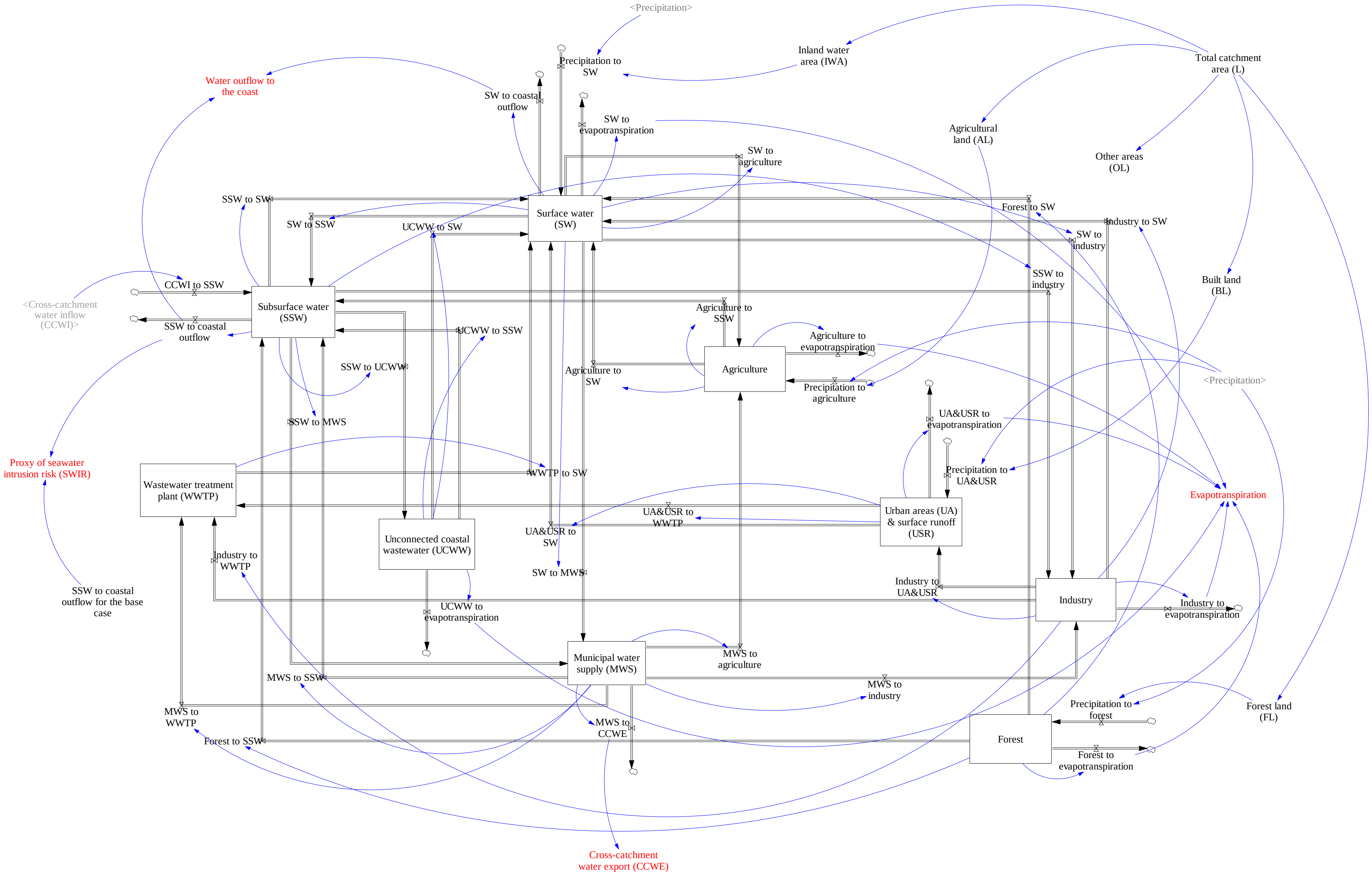

Figure 25. SF structure of SD sub-model 1 in MAL3 developed in Vensim software. The main outputs of the model are shown with red font color.

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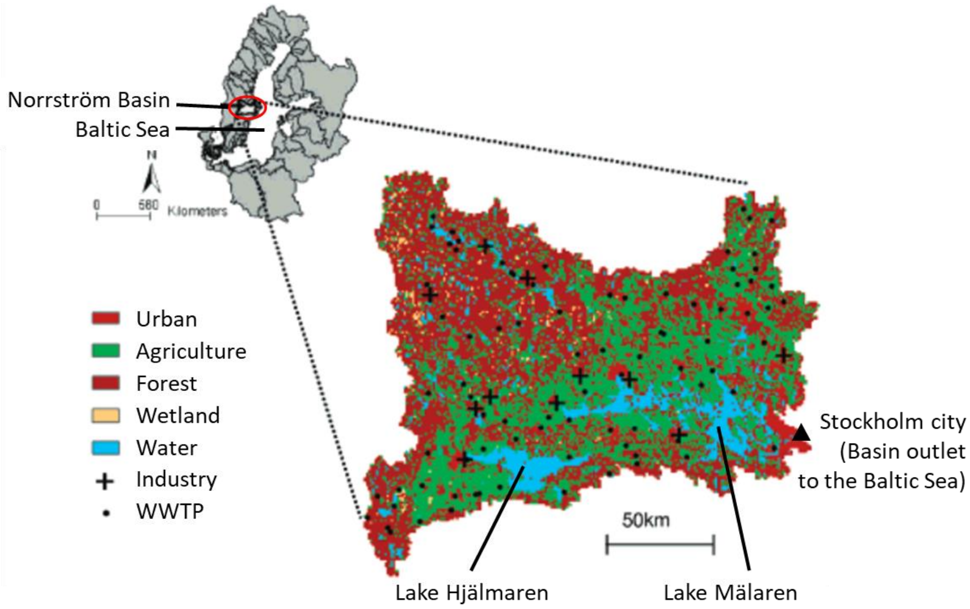

Figure 26. Location and land-use map of the Norrström drainage basin within Sweden, representing the whole inland study area in MAL3 with its coastal regions to the Baltic Sea. Modified figure based on Figure 1 in Lindgren et al. (2007).

Table 13 summarizes the published peer-reviewed outcomes of an integrated input-output analysis (IOA) specifically for recent-current conditions in MAL3 (Baresel and Destouni, 2005; Cseh, 2009). IOA is an inter-system/sectoral equilibrium type of modelling, investigating the interactions between several sectors in the basin, concerning natural water cycle, man-made water systems and anthropogenic water impacts. Table 13 is developed as a water balance constrained matrix using various resources (shown with color coding in this table) and applying IOA to fill the gaps in the table for MAL3. Thus, Table 13 identifies average annual total water flux from each natural water system and inland/coastal sector and its partitioning among other systems/sectors. This table is used to quantify interactions in sub-model 1 with precipitation and cross-catchment water inflow (CCWI) as input variables (the last two rows in Table 13) and evapotranspiration, water outflow to the coast and cross-catchment water export (CCWE) as output variables (the last three columns except the total column in Table 13). Values presented in the total column in Table 13 for precipitation and CCWI are used directly in sub-model 1 to quantify these two input variables. Output variables are calculated based on outflow rate variables from contributing stock variables. Surface water (SW) and subsurface water (SSW) as natural systems, and agriculture, industry, forest and forestry, MWS, unconnected coastal wastewater (UCWW), urban surface runoff (USR) and WWTP as inland/coastal sectors are structured as stock variables in sub-model 1 (Figure 25). The value of these stock variables is quantified based on their connected inflow and outflow rate variables as:

$$Stock_t = Stock_{t-1} + dt \cdot \sum_{i=1}^{n} Inflow_{i,t} - dt \cdot \sum_{j=1}^{m} Outflow_{j,t} \qquad \begin{matrix} t = 2, 3, 4, \ldots, 100 \\ Stock_1 = Stock_{initial} \end{matrix} \qquad (44)$$

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 m³/year), $Outflow_{j,t}$ is the outflow rate to stock/system/sector j at time t (million m³/year), dt is selected time step for the model as one year, n and m are the total number of stocks/systems/sectors that deliver and take water from the specific stock, respectively.

Table 13. Long-term annual average water flow exchanges (10^6 m³/year) between natural water systems and inland/coastal sectors used to quantify SD sub-model 1 for the base case condition in MAL3. Modified table based on Table 2 in Cseh (2009).

From \ To	Surface water (SW)	Subsurface water (SSW)	Wastewater treatement plant (WWTP)	Industry	Municipal water supply (MWS)	Urban areas and surface runoff (UA&USR)	Forest	Agriculture	Unconnected coastal wastewater (UCWW)	Evapotranspiration	Water outflow to the coast	Cross-catchment water exports (CCWE)	Total
SW	0	711	0	82	220	0	0	6	0	1047	5140	0	7206
SSW	3765	0	0	3	20	0	0	0	10	0	250	0	4048
WWTP	116	0	0	0	0	0	0	0	0	0	0	0	116
Industry	155	0	13	0	0	2	0	0	0	25	0	0	195
MWS	0	10	45	110	0	0	0	6	0	0	0	69	240
UA&USR	138	0	58	0	0	0	0	0	0	365	0	0	561
Forest	823	1947	0	0	0	0	0	0	0	4571	0	0	7341
Agriculture	549	1329	0	0	0	0	0	0	0	3314	0	0	5192
UCWW	3	5	0	0	0	0	0	0	0	2	0	0	10
Precipitation	1657	0	0	0	0	559	7341	5180	0				14737
Cross-catchment water inflow (CCWI)	0	46	0	0	0	0	0	0	0				46

Results of IOA analysis
Results of other types of scientific analysis
Reasonable estimates that allow closure of mass balance within the entire matrix
Relatively uncertain estimates that allow closure of mass balance within the entire matrix

For each stock variable in sub-model 1, the value of $Stock_{initial}$ is considered equal to the values presented in the total column in Table 13. 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:

$$Outflow_t = Fraction \times Stock_t \qquad t = 1, 2, 3, \dots, 100 \qquad (45)$$

where, $Fraction$ is an auxiliary variable with a constant value in the range of [0, 1] for all time steps (1/year). The multiplication structure defined in Equation (45) is applied to quantify the values of inflow and outflow rates for different stock variables in sub-model 1 for MAL3. Therefore, there is a specific $Fraction$ variable connected to each inflow/outflow rate variable in this sub-model. Table 14 shows the normalized matrix of Table 13 based on the total column, and is used to quantify $Fraction$ variables in sub-model 1 according to the following conditions:

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Table 14. Fractions used to quantify inflow/outflow rate variables connected to stock variables for the base case condition in SD sub-model 1 in MAL3. Blue and yellow rows include fractions related to inflow/outflow rate variables for natural water systems and inland/coastal sectors, respectively. Green rows and red columns include fractions related to inflow/outflow rate variables associated with main water input components and water output components, respectively.

	SD sub-model 1	Stock variables									Output variables		
SD sub-model 1	From \ To	Surface water (SW)	Subsurface water (SSW)	Wastewater treatement plant (WWTP)	Industry	Municipal water supply (MWS)	Urban areas and surface runoff (UA&USR)	Forest	Agriculture	Unconnected coastal wastewater (UCWW)	Evapotranspiration	Water outflow to the coast	Cross-catchment water exports (CCWE)
Stock variables	SW	0	0.099	0	0.011	0.031	0	0	0.001	0	0.145	0.713	0
	SSW	0.930	0	0	0.001	0.005	0	0	0	0.002	0	0.062	0
	WWTP	1.000	0	0	0	0	0	0	0	0	0	0	0
	Industry	0.795	0	0.067	0	0	0.010	0	0	0	0.128	0	0
	MWS	0	0.042	0.188	0.458	0	0	0	0.025	0	0	0	0.288
	UA&USR	0.246	0	0.103	0	0	0	0	0	0	0.651	0	0
	Forest	0.112	0.265	0	0	0	0	0	0	0	0.623	0	0
	Agriculture	0.106	0.256	0	0	0	0	0	0	0	0.638	0	0
	UCWW	0.300	0.500	0	0	0	0	0	0	0	0.200	0	0
Input variables	Precipitation	0.112	0	0	0	0	0.038	0.498	0.351	0			
	Cross-catchment water inflow (CCWI)	0	1.000	0	0	0	0	0	0	0			

- If an outflow rate from a stock variable is an inflow rate to another stock variable (e.g., the outflow rate of “SW to agriculture” from SW stock in Figure 25 that is an inflow rate to agriculture stock), values highlighted with red surrounding box in Table 14 are used as the $Fraction$ variable associated with the outflow rate (e.g., value of 0.001 in the first row is used as the $Fraction$ variable to calculate the outflow rate of “SW to agriculture”).
- If an outflow rate from a stock variable contributes to model output variables (e.g., the outflow rate of “SW to coastal outflow” from SW stock in Figure 25 that contributes to total “Water outflow to the coast”), values highlighted with yellow surrounding box in Table 14 are used as the $Fraction$ variable associated with the outflow rate (e.g., value of 0.731 in the first row is used as the $Fraction$ variable to calculate the outflow rate of “SW to coastal outflow”).
- If an inflow rate to a stock variable is associated with model input variables (e.g., the inflow rate of “Precipitation to SW” from precipitation to SW stock in Figure 25), values highlighted with blue surrounding box in Table 14 are used as the $Fraction$ variable and multiplied by the total value of the associated input variable to calculate the inflow rate (e.g., value of 0.112 in the first row is used as the $Fraction$ variable to calculate the inflow rate of “Precipitation to SW”).

Values of $Fraction$ variables can change with time, however, they are kept constant over the simulation time period (100 years starting from 2010) in the base case scenario simulation in sub-model 1, but they vary to different degrees among other scenarios.

Output variables of evapotranspiration, water outflow to the coast and CCWE in sub-model 1 are calculated as the total of outflow rate variables from contributing stock variables. For example, water outflows to the coast at time step t ($Water\ outflow\ to\ the\ coast_t$, million m^3/year), is calculated as ($t = 1, 2, 3, \ldots, 100$):

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$$\begin{aligned} Water\ outflow\ to\ the\ coast_t &= SW\ to\ coastal\ outflow_t + SSW\ to\ coastal\ outflow_t \\ &= 0.713 \times SW_t + 0.062 \times SSW_t \end{aligned} \tag{46}$$

where, $SW\ to\ coastal\ outflow_t$ and $SSW\ to\ coastal\ outflow_t$ are outflow rates from SW and SSW (million m^3/year) respectively at time step t contributing to coastal outflow, and SW_t and SSW_t are values of SW and SSW stock variables (million m^3) respectively at time step t.

Published peer-reviewed modelling approach of seawater intrusion into coastal groundwater (Mazi et al., 2016) and to associated critical thresholds/tipping points related to coastal subsurface flow (Mazi et al., 2013 and 2014) is used to develop and quantify a proxy of change in critical seawater intrusion risk (SWIR) in sub-model 1. As explained in COASTAL Deliverable D13 for quantification of the sub-model 1 (Viaene et al., 2020), a relevant proxy, with change sign consistency in quantification of increased (decreased) risk of critical seawater intrusion, is developed and used to quantify seawater intrusion risk as:

$$SWIR = 1 - \frac{Q_{SDG2}}{Q_{SDG1}} \tag{47}$$

where, Q_{SDG1} and Q_{SDG2} are submarine groundwater discharge to the sea under a base condition and a new changed condition (million m^3/year), respectively. Based on Equation (47), positive (negative) values indicate decrease (increase) of Q_{SDG2} compared to Q_{SDG1} under a new changed condition, and thereby increased (decreased) risk of critical seawater intrusion into coastal groundwater resources. In sub-model 1, Q_{SDG1} is considered as the amount of subsurface water flow to the coast for the base case condition that is equal to 250 million m^3/year based on Table 13.

With all input variables and water flow partitioning fraction variables being quantified, output variables in sub-model 1 as evapotranspiration, water outflow to the coast, CCWE and proxy of SWIR are calculated for the base case condition. Any change in drivers, identified in Table 12, such as precipitation and agricultural, urban and forest land areas, results in development of a new balanced condition in the MAL3 system and values of output variables can be evaluated under the new developed system condition through sub-model 1.

5.3.2.2 Sub-model 2. Land-sea inter-sectoral and coastal waterborne nutrient exchange

5.3.2.2.1 Quantified key land-sea interactions and feedback structures in sub-model 2

Long-term nutrient load development within the Norrström drainage basin and to its Baltic coastal regions is largely controlled by delayed load contributions from legacy sources (Baresel and Destouni, 2006; Lindgren et al., 2007; Darracq et al., 2008; Destouni and Jarsö, 2018). In addition, regional nutrient loads to inland and coastal waters may increase in future as a result of more intensive human activities (Destouni and Darracq, 2009). Even without any such human-driven concentration increases, water flow and its likely future changes also play an important role in the development of nutrient loading from inland to coastal recipient waters. Nutrients are mainly transported through water flows and the linked flow and load changes depend greatly on future hydro-climatic change as well as changes in inter-system/sectoral water flow exchanges due to various possible developments in human and sectoral activities. Therefore, scenarios of possible increasing

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water use in the MAL3 coastal region, addressed by sub-model 1, are in sub-model 2 associated with increasing waterborne nutrient loads from different water using/impacting sectors through natural surface and subsurface water systems to inland, coastal and further to marine environments (Baresel and Destouni, 2005).

Sub-model 2 investigates the contributions of various inland/coastal sectors to coastal nutrient loads through the natural surface and subsurface waters, and their possible associated changes, e.g., due to overall hydro-climatic change and/or human water pressure changes in MAL3. In turn, this sub-model can also represent feedbacks from changes in coastal nutrient loads and associated coastal water quality and ecosystem conditions to sectoral nutrient exchanges and associated maximum allowable nutrient inputs to the coastal catchment area, under policy responses for achieving target water quality status in the coastal waters and the Baltic Sea. Such development scenarios can be assessed based on the relationships between water flux and nutrient load in sub-model 2.

Figure 27 illustrates two different SF structures for nutrient release from SSW system and agriculture sector as two parts of sub-model 2. A similar SF structure is created for SW system and other inland/coastal sectors separately according to their interactions represented in Table 13 (published for the current-recent situation in MAL3) to model their nutrient release. All SF structures are then connected to develop sub-model 2 for which the whole SF structure has become too complex to be presented here. Such a complex SF structure supports sub-model 2 to simulate nutrient exchanges (release from and load to) for natural water systems and inland/coastal sectors and through them for coastal region in MAL3. The same natural water systems and inland/coastal sectors as sub-model 1 are considered in sub-model 2 with the main variables that were listed in COASTAL Deliverable D13 – Section 3.3.7 (Viaene et al., 2020) and are also presented here in Table 15 with possibly some updates based on the sub-model progress in MAL3. In this sub-model, nutrient (nitrogen and phosphorus) concentrations in SW and SSW and in inflows and outflows for WWTP along with cross-system/sectoral water flux exchanges (calculated in sub-model 1) are considered as model input variables. As identified in Table 15, nutrient loads to natural water systems and through them to the coast as well as waterborne nutrient exchanges between natural water systems and inland/coastal sectors are considered as the main model output variables.

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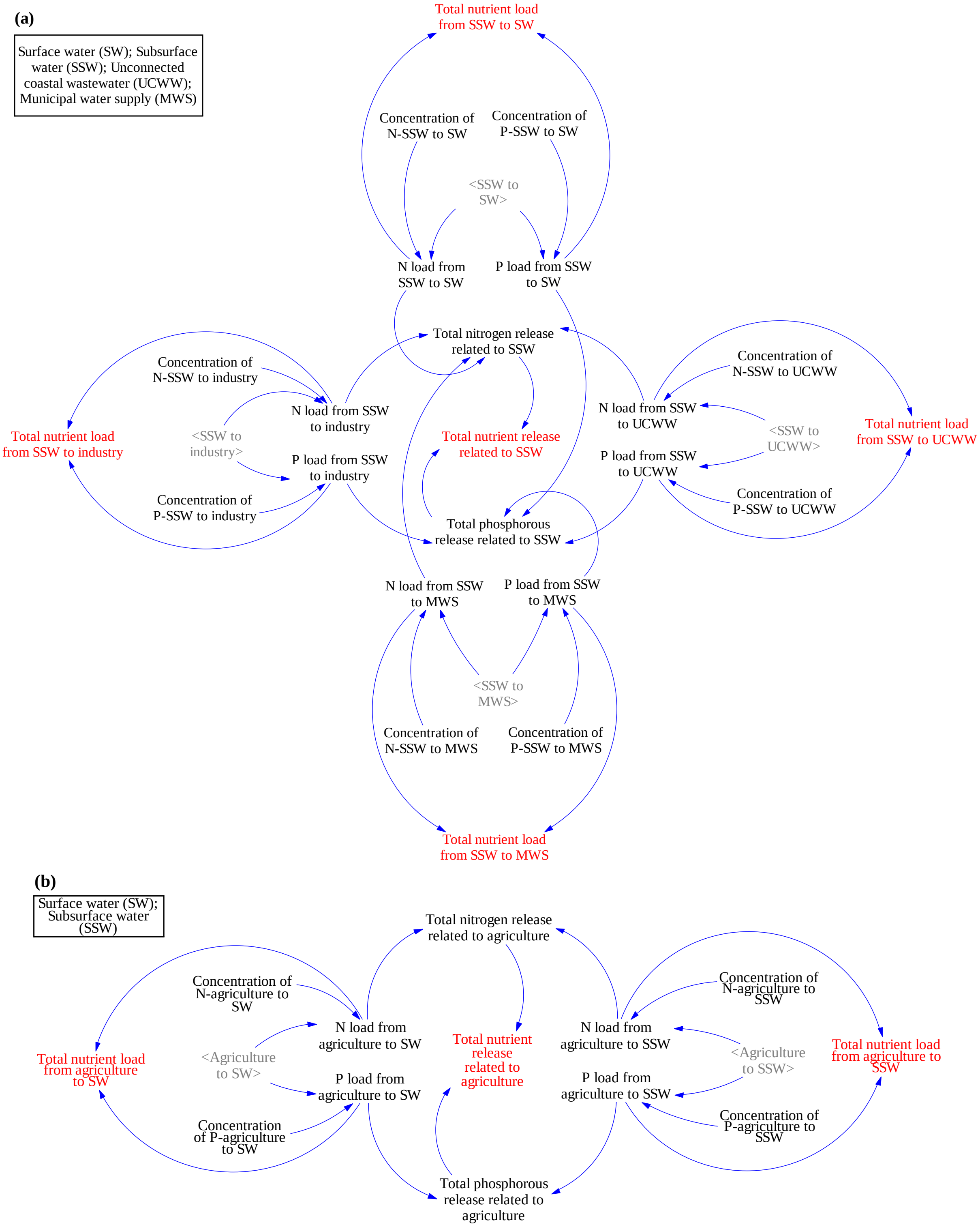

Figure 27. SF structure of nutrient (N: nitrogen, P: phosphorus) releases from subsurface water system (SSW) as a natural system (a) and from agriculture as an inland/coastal economic sector (b) to connected natural systems and inland/coastal sectors in SD sub-model 2 for MAL3 developed in Vensim software. The main outputs in these parts of the model are shown with red font color.

Table 15. Main variables in SD sub-model 2 for MAL3 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant, SW: surface water, SSW: subsurface water, MWS: municipal water supply, UCWW: unconnected coastal wastewater, USR: urban surface runoff, WWTP: wastewater treatment plant, CCWI: cross-catchment water inflow, CCWE: cross-catchment water export).

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

5.3.2.2.2 Outline of quantitative information to support sub-model 2

Nutrient input concentrations to SW are quantified as input variables in sub-model 2, based on published peer-reviewed data in MAL3, where the long-term average nutrient concentrations (C, mg/lit) for the period 1994-2010 are, by definition, determined as (Bring et al., 2015):

$$C = \frac{L}{Q} \tag{48}$$

where, L and Q are annual average values of reported monitored annual surface nutrient loads (tonnes/year) and annual average SW discharges (million m^3/year), respectively, from the Baltic Proper drainage basin which includes the Norrström drainage basin as the main contributor (HELCOM, 2013b). Equation (48) is a general representation of the relationship between water flow, nutrient concentration and associated waterborne nutrient load. Based on this equation, long-term average nutrient concentration levels in SW flowing through the Norrström drainage basin to the MAL3 coastal region and eventually the Baltic Sea are calculated as 1.43 mg/lit for total nitrogen and 0.04 mg/lit for total phosphorus (Bring et al., 2015). These average concentration levels are relatively stable temporally or subject to only mild short-term variations and slow long-term changes (e.g., Destouni et al., 2017; Destouni and Jarsjö, 2018). 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

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levels are considered as inputs in sub-model 2 to further quantify nutrient loads from SW to SSW, coastal region and inland/coastal sectors.

The actual data-driven published nutrient concentration levels in SW in MAL3 are associated with around 80% of total coastal catchment area on land (Hannerz and Destouni, 2006). The remaining 20% of the total coastal catchment area mainly include the diffuse subsurface flow contributions to coastal nutrient loads which is not monitored. In order to fill the data gap on nutrient concentration levels in subsurface coastal flows, developed and published data-based regression relationships for nutrient loads with population density, Equations (49) and (50) respectively, are used to make a reasonable estimation (Levi et al., 2018):

$$For\ nitrogen \quad \rightarrow C_N \approx 10.0324\ \times pop + 0.4412 \qquad R^2 = 0.82 \tag{49}$$

$$For\ phosphorus \ \rightarrow C_P \approx 0.0012\ \times pop + 0.0238 \qquad R^2 = 0.90 \tag{50}$$

where, C_N and C_P are total nitrogen and total phosphorus concentration levels in surface water flows (mg/lit), respectively, and pop is population density (people/km^2). These relationships are developed based on monitored data on catchment scale in various parts of the world including the Baltic region. They can also be used in unmonitored catchment areas and their high coefficient of determination highlights their high estimation accuracy. Knowing population distribution between monitored and unmonitored coastal catchment areas and thus population density in unmonitored coastal regions, nutrient concentration levels mainly associated with subsurface coastal flows can be estimated.

The unmonitored coastal catchment areas in Sweden contain 55% of the total population while the rest are living in the more inland monitored areas (Hannerz and Destouni, 2006). The ratio of population density in unmonitored (pop_{um}) to monitored (pop_m) catchment coastal area is then calculated as $pop_{um}/pop_m = (55P/20A)/(45P/80A) = 5$. Rearranging the equations, provides the regression-based relationships as Equations (51) and (52), from which nutrient input concentration levels to subsurface water can be estimated, given the conditions $pop_{um} = 5\ pop_m$, $C_{N,m} = 1.43$ mg/lit and $C_{P,m} = 0.04$ mg/lit:

$$\begin{aligned} For\ nitrogen \quad \rightarrow C_{N,um} &\approx 10.0324\ \times pop_{um} + 0.4412 \\ &= 5(10.0324\ \times pop_m + 0.4412) - 1.7648 \\ &\approx 5\ C_{N,m} - 1.7648 \approx 5 \times 1.43 - 1.7648 \approx 5.38\ \ mg/lit \end{aligned} \tag{51}$$

$$\begin{aligned} For\ phosphorus \ \rightarrow C_{P,um} &\approx 0.0012\ \times pop_{um} + 0.0238 \\ &= 5(0.0012\ \times pop_m + 0.0238) - 0.0952 \\ &\approx 5\ C_{P,m} - 0.0952 \approx 5 \times 0.04 - 0.0952 \approx 0.10\ \ mg/lit \end{aligned} \tag{52}$$

In sub-model 2, long-term average nutrient input concentrations to unmonitored subsurface water are obtained from the above equations and considered as 5.38 mg/lit for total nitrogen and 0.1 mg/lit for total phosphorus. The higher nutrient input concentrations for subsurface water relative to those for surface water are due to the contributions of subsurface nutrient legacy sources accumulated in soil and sediments of the MAL3 coastal region.

Reported nutrient concentration levels in outflows from WWTP (C_{out}) in the Baltic Proper water management district (including the Norrström drainage basin) are directly used to quantify relevant variables in sub-model 2 as 9.1 and 0.21 mg/lit for nitrogen and phosphorus, respectively (Swedish Environmental

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Protection Agency - Naturvårdsverket, 2016). Based on the reported levels of removal efficiency for nitrogen and phosphorus within the same report as 78 and 96%, respectively, nutrient concentration levels in inflows to WWTP (C_{in}) are calculated and used in sub-model 2 as:

$$For\ nitrogen \quad \rightarrow C_{N,in} = 9.1/(1-0.78) \approx 41.36 \quad mg/lit \tag{53}$$

$$For\ phosphorus \quad \rightarrow C_{P,in} = 0.21/(1-0.96) \approx 5.25 \quad mg/lit \tag{54}$$

Based on the above, long-term average nutrient concentration inputs to WWTP from various natural systems and inland/coastal sectors are in sub-model 2 considered as 41.36 mg/lit for nitrogen and 5.25 mg/lit for phosphorus. Obviously, concentrations in inflows to WWTP are higher than in outflows from WWTP. In conclusion, Table 16 summarizes nutrient concentration levels used as inputs to sub-model 2 to simulate waterborne nutrient loads to the MAL3 coastal regions and nutrient exchanges among natural water systems and inland/coastal sectors in MAL3. Since there is no data reported on nutrient concentration inputs to natural water systems from some of the sectors, such as industry, MWS, agriculture and forestry, these are considered the same as the average nutrient concentration levels in SW and SSW.

Table 16. Nutrient concentration levels (mg/lit) for interactions between various natural water and coastal systems and inland/coastal sectors used in SD sub-model 2 in MAL3.

Concentration level (mg/lit) for:	From \ To	Surface water (SW)	Subsurface water (SSW)	Wastewater treatement plant (WWTP)	Industry	Municipal water supply (MWS)	Urban areas and surface runoff (UA&USR)	Forest	Agriculture	Unconnected coastal wastewater (UCWW)	Water outflow to the coast	Cross-catchment water exports (CCWE)
Nitrogen	SW	0	1.43	0	1.43	1.43	0	0	1.43	0	1.43	0
	SSW	5.38	0	0	5.38	5.38	0	0	0	5.38	5.38	0
	WWTP	9.10	0	0	0	0	0	0	0	0	0	0
	Industry	1.43	0	41.36	0	0	1.43	0	0	0	0	0
	MWS	0	5.38	41.36	1.43	0	0	0	1.43	0	0	1.43
	UA&USR	1.43	0	1.43	0	0	0	0	0	0	0	0
	Forest	1.43	5.38	0	0	0	0	0	0	0	0	0
	Agriculture	1.43	5.38	0	0	0	0	0	0	0	0	0
	UCWW	1.43	5.38	0	0	0	0	0	0	0	0	0
Phosphorus	SW	0	0.04	0	0.04	0.04	0	0	0.04	0	0.04	0
	SSW	0.10	0	0	0.10	0.10	0	0	0	0.10	0.10	0
	WWTP	0.21	0	0	0	0	0	0	0	0	0	0
	Industry	0.04	0	5.25	0	0	0.04	0	0	0	0	0
	MWS	0	0.10	5.25	0.04	0	0	0	0.04	0	0	0.04
	UA&USR	0.04	0	0.04	0	0	0	0	0	0	0	0
	Forest	0.04	0.10	0	0	0	0	0	0	0	0	0
	Agriculture	0.04	0.10	0	0	0	0	0	0	0	0	0
	UCWW	0.04	0.10	0	0	0	0	0	0	0	0	0

Peer-reviewed published nutrient concentration level in surface water
Estimated nutrient concentration level in subsurface water
Reported nutrient concentration level in wastewater inflows to wastewater treatment plants
Reported nutrient concentration level in treated wastewater outflows from wastewater treatment plants

Based on actual data-given, published and peer-reviewed nutrient concentration behavior 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), average concentration levels are considered constant over time in each development/change scenario (including the base case condition), but will vary between scenarios in order to represent various possible solution scenarios that might change these levels and investigate how such changes then propagate through and impact the whole modelled land-coast system in the different scenarios.

5.3.3 Synthetic reflection on the quantification process for the different SD sub-models

The two developed sub-models in MAL3 are mainly quantified using established openly available data, model equations and results, and modeling approaches that are published in relevant official national assessment reports or peer-reviewed scientific publications. Key surface and subsurface water systems, and various inland/coastal sectors (agriculture/agro-tourism, forest/ecosystem and forestry, urban/urban tourism, industry, and WWTP) are considered in both sub-models along with implications of urban storm water handling and coastal unconnected wastewater handling for sustainable coastal development in MAL3.

In sub-model 1, the outcomes of an input-output analysis quantify long-term annual average water exchanges between natural water systems and inland/coastal sectors in the coastal region. In this sub-model, seawater intrusion risk in the MAL3 coastal region is addressed by a proxy of change in critical intrusion risk, which is developed following a peer-review published modeling approach for assessing seawater intrusion into coastal groundwater under multiple change pressures. While all required quantitative information in sub-model 1 is available, there are real data gaps with regard to nutrient concentration inputs for the quantification of sub-model 2 in MAL3. The only available nutrient concentration levels to be directly used in sub-model 2 are associated with site-specific monitored surface waters (shown to be relatively stable over time) as well as outflows from site-specific WWTPs. Therefore, these nutrient concentrations in surface waters are used to quantify the nutrient load exchanges (loads to and releases from) related to the SW component in sub-model 2. Some nutrient exchanges between inland/coastal sectors are also reasonably quantified using the same nutrient concentrations as in the waters in sub-model 2. Nutrient input concentrations for unmonitored subsurface waters are estimated using data-given regression relationships developed at catchment scale in MAL3 and used in sub-model 2 to quantify the nutrient load exchanges (loads to and releases from) related to the SSW component. Nutrient releases from WWTPs are quantified in sub-model 2 using relevant reported nutrient concentration levels. Also, reported nutrient removal efficiency in WWTPs is used to estimate the nutrient concentrations and associated nutrient loads into the WWTPs from various sectors in sub-model 2.

The two developed SD sub-models in MAL3 are fully quantified, connected and running for the base case conditions. These sub-models also support evaluation of system behavior in relation to the addressed water problems under possible local/regional development/change scenarios.

5.3.4 Plan for scenario analysis using the SD sub-models

The developed SD sub-models in MAL3 will be used to test various types of local/regional development/change scenarios, as listed in Table 17 and address the scenario implications for land-sea interactions and associated water quantity and quality changes in the region. In general, the types of expected results from scenario analysis by the MAL3 SD sub-models are associated with quantification of water availability/exchanges (sub-model 1) and water quality relating to seawater intrusion risk (sub-model 1) and waterborne nutrient loads/exchanges (sub-model 2) for various hydro-climatic and sector

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development/change scenarios of relevance for the region. These expected scenario analysis results and their implications can be related to the key overarching frameworks of the European Green Deal (EC, 2020; according to topics in Figure 9), the UN sustainable development goals (SDGs) in Agenda 2030 (UN, 2015; Figure 10), the SSPs of global change scenarios (Riahi et al., 2017; Figure 11), and the marine spatial planning of Sweden specifically for the Baltic Sea proper (Swedish Agency for Marine and Water Management, 2019), as outlined in Table 17.

Table 17. Types of scenarios that may be testable/tested through the SD modelling in MAL3 and their relations to topics/scenarios in the listed overarching frameworks (European Green Deal topics, Figure 9; SDGs: UN Sustainable Development Goals in Agenda 2030, Figure 10; SSPs: Shared Socioeconomic Pathways, Figure 11; Topics in applicable MSP: Marine Spatial Plan).

Types of scenarios for SD modelling	Indicate if the scenarios can be related to any of the overarching frameworks and briefly to which framework topics/scenarios			
	Topic in European Green Deal	SDGs	SSP scenarios	Topic in MSP
Hydro-climatic change and its impact on water availability and quality	Yes Protecting Nature, Eliminating Pollution, Climate Pact/Law	Yes SDGs 6, 13, 14	Yes Any scenario through RCP-climate scenario relations	Yes Swedish Baltic Sea plan – Reinforcement of ecosystem services
Agricultural & associated tourism developments	Yes Protecting Nature, Eliminating Pollution, From Farm to Fork, Climate Pact/Law	Yes SDGs 6, 13, 14, 15	Yes Any scenario through land-use, GDP relations	Yes Swedish Baltic Sea plan – Reinforcement of ecosystem services
Urbanization & associated tourism developments	Yes Protecting Nature, Eliminating Pollution	Yes SDGs 6, 11, 14	Yes Any scenario through urbanization, population, GDP relations	Yes Swedish Baltic Sea plan – Reinforcement of ecosystem services
National and international environmental regulations and agreements	Yes Protecting Nature, Eliminating Pollution	Yes SDGs 6, 14, 15	Potentially To be determined how	Yes Swedish Baltic Sea plan – Reinforcement of ecosystem services
Combinations of the above-mentioned scenarios	Yes Protecting Nature, Eliminating Pollution, Climate Pact/Law, From Farm to Fork	Yes SDGs 6, 11, 13, 14, 15	Yes Any scenario through RCP-climate scenario, land-use, GDP, urbanization, and population relations	Yes Swedish Baltic Sea plan – Reinforcement of ecosystem services

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5.4 Multi-Actor Lab 4. Charente River Basin (Atlantic Region) - France

5.4.1 Introduction and problem scope for land-sea SD modelling

The part of the Charente River watershed 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 28). 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. Pressure on water resources affects both quality (i.e. pollution by nitrate and pesticides, viruses) and quantity (impact on natural environments and availability of drinking water). 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. Activities carried by agriculture with irrigation of crops (mainly maize), use of Nitrogen (in particular with cereal crops) and pesticides (notably on wines used for Cognac production) and domestic use have a significant impact on 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.

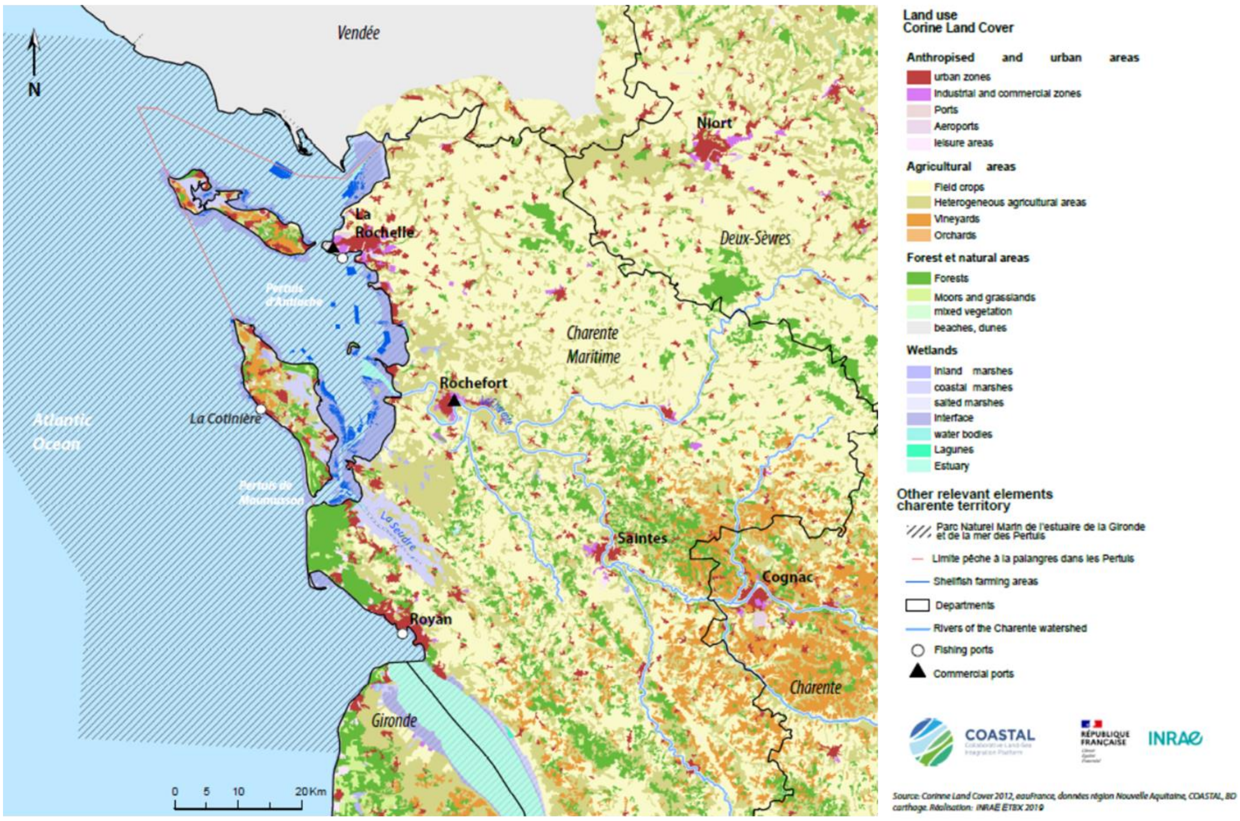

Figure 28. Map of the land-sea system for MAL4

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 upstream location, is only accessible by smaller vessels (Viaene et al., 2020).

In the coastal region of the MAL4, two main issues were identified through workshops (Tiller et al., 2019a and 2019b) involving water and land availability, and economic sectors related on these resources. The land-sea interactions we consider in the modelling are (Viaene et al., 2020):

- 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 resulting in seasonal population increase with a significant water demand in summer and the irrigated crops development;
- Interactions between the development of cash crops in the hinterland and the development of trading port activities causing infrastructure investments;
- Interactions between the development of organic crops with crop diversification, development of short supply chains and the needs for infrastructure development (specific storage); and
- Interactions between changes of farming systems (irrigated to non-irrigated, conventional to organic farming) and the coastal water quality (Nitrogen and pesticides).

The causal loop diagram (CLD) of the whole land-sea system served as a basis for developing a stock-flow (SF) model of the overall system that was split up into different sub-models considered relevant to tackle the main issues addressed during the workshops (Tiller et al., 2019a and 2019b). Special attention was given to the water sub-model because of the central importance attached to the water issue as the main concern.

All the variables of the CLD were retained and defined as Level (or Stock) when they represent accumulations or depletions over time. Regulation thresholds are defined as constant variables (e.g. withdrawal authorization, instream flow requirements, etc.). All other variables are defined either as flows connected to stocks or as auxiliaries. Some variables like climate change and its impact on air temperature increase and evapotranspiration of crops are considered as exogenous variables affecting the water system but not affected by it. Soft variables (impact of one variable on another) were built according to available literature. When no reference was found in bibliography, we made assumptions on the relationship between variables (shape of the function) that will be discussed during the second round of workshops as part of WP1.

As shown in Figure 29, Links between the water sub-model and agriculture sub-model rely on crops water demand, on the impact of farming systems on environmental pressure indicators (Treatment Frequency Index, Nitrogen applied and associated Nitrogen fluxes simulated in previous studies with the Soil and Water Assessment Tool (SWAT) model (Vernier et al., 2016). Links between shellfish production sub-model and the water sub-model rely on water quality and its relation with the frequency of major causes of mortality (virus occurrence), while oyster growth is related to salinity required and Nitrogen concentration in coastal waters.

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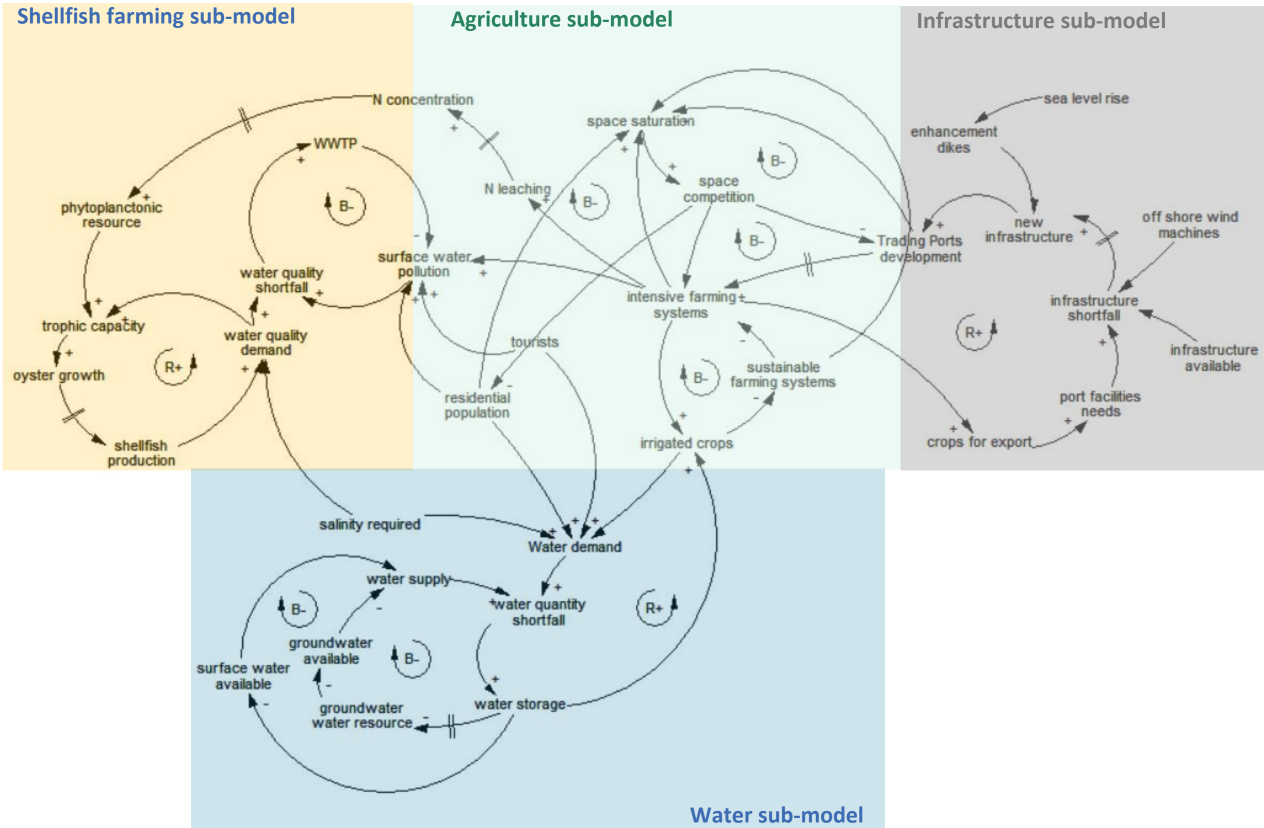

Figure 29. CLD of the main land-sea interactions and links between sub-models in MAL4 (Viaene et al., 2020).

5.4.2 Quantified SD sub-models

The overall problem within the MAL4 case study can be formulated in the terms of land-sea interdependencies and competition for water and space with particularly (i) significant environmental pressures from economic activities mainly agriculture, and (residential and summer) population increase on water resources quality and quantity, and (ii) the development of urban coastal population and tourism with pressure on protected areas and wetlands. Effects of climate change may result in sea level rise (with increased risk of marine submersion and soil salinization) because of the flatness of the coast, and the presence of important wetlands. Finally, the two major ports in the area rely on local agricultural products for a sizeable portion of their business and changes in agricultural systems in the hinterland may affect their activities.

All sectors of activities are going to face constraints on water resources and should develop in a sustainable way. Because of the high dependency between the downstream activities and upstream activities with regard to water quantity and quality, there will be increasing pressure on upstream activities. Coastal water quality will increasingly depend on agriculture and population. Attractiveness of coastal areas will still drive summer tourism development until coastal congestion will decrease attractiveness. There will be a growing demand for drinking water, and needs for water treatment plants (waste and drinking water) with higher capacities. The development of ports relies on inland agricultural production and changes in the hinterland will affect their strategic development. Climate change will particularly affect coastal zones increasing flood and drought risks, sea level rise with submersion risks

The list of sub-models developed for addressing the aforementioned issues are presented in Table 18.

Table 18. List of developed SD sub-models, their associated problems and their quantification status (fully/partially/not yet quantified) in MAL4.

No.	Title of SD sub-model	Addressed problems	Status of quantification
1	Water	Water availability, water quality, impacts of tourists, agriculture on water	Fully quantified but calibration is not completed.
2	Oyster farming	Water quality and impact on oyster production, market demand	Fully quantified but calibration is not completed. Adjustments might be necessary after workshops with stakeholders.
3	Agriculture	Farming system changes, shift to organic farming, crop diversification and abandon of irrigation	Fully quantified but calibration is not completed. Adjustments might be necessary after workshops with stakeholders.
4	Infrastructure (Dikes)	Risk perception and building of embankments to avoid coastal flooding, submersion of agricultural land	Almost entirely quantified; However, some structural adjustments needed and to be completed after meeting with experts and workshops.

5.4.2.1 Sub-model 1. Water

5.4.2.1.1 Quantified key land-sea interactions and feedback structures in sub-model 1

The key challenges to be addressed with sub-model 1 are to: (i) quantify interactions between the different economic activities focusing on their use of water resources; (ii) assess how groundwater, surface water and reservoirs can respond to water demand variability; (iii) assess the impact of economic activities on water quality, and (iv) assess the impact of water shortage on farming systems and vice versa.

Dynamic hypotheses regarding this sub-model are: (i) climate change will lead to warmer and drier summers and changes in rainfall repartitioning; (ii) all domestic and economic activities will have to deal with water scarcity; and (iii) increasing coastal population will put additional pressure on water resources affecting activities that depend on it. The objective of the water sub-model is, first to consider physical processes of the water cycle within the Charente river basin, second to propose a quantification of interactions between the different rural and coastal human activities focusing on the use of water resources. To achieve these goals, we quantified interconnections between variables identified with stakeholders (Tiller et al., 2019a and 2019b).

The nature of the variables in the water sub-model is of different types: (i) stochastic variables such as rainfall and temperature (evapotranspiration), here exogenous variables; (ii) delay variables such as the recharge of groundwater, surface runoff, surface and groundwater exchanges, linked mainly to physical processes; and (iii) adjustment variables intended to manage the water demand. These adjustment variables could be long-term adjustment variables like investments (construction of reservoirs, increase of the capacity of drinking water treatment plants or waste water treatment plants), short-term adjustment variables between years (withdrawal authorizations), or within a year for managing low-waters (bans on irrigation with various lengths of time).

In the context of System Dynamics (SD), we considered as stocks the groundwater, the water in soil, the surface water, the dam water storage, the streams, the water in marshes, the reservoirs water storage for irrigation, and the coastal water salinity level. The objective was to highlight interactions between these

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different stocks and their use in the hinterland and assess to what extend this use would affect water salinity in coastal waters.

Outside the boundaries, we have developed two small SF structures for population and agriculture. They are intended, however, to link later the agriculture sub-model to the water sub-model.

Flow variables represent water flows between stocks (groundwater recharge, water rise, runoff, infiltration, water release from dams, withdrawals for domestic use, agriculture) and changes in coastal water salinity. Delays in flows between stocks have been considered to take into account physical processes.

We developed the water sub-model with the purpose of assessing how the variability of water demand within a year and between years may affect economic activities and how water stocks are used to satisfy water needs. Agriculture and tourism need water at the same period of time while shellfish farming need a range of salinity in coastal waters. Upstream of the river Charente, we merge the storage capacity of the two dams built to back up low water flows. Downstream, we merged the capacities of the different water reservoirs for irrigation. Extension of their capacities (although controversial) is considered as a solution to supply agriculture water needs in summer and this will be assessed in scenarios. We took into account regulations such as minimum river flows, requirements for ecosystem, withdrawal authorizations, or irrigation bans. As auxiliary variables, they will be useful for simulating scenarios with stakeholders. Unlike other sub-models in MAL4, where the time unit used is the year, the water sub-model is run on a monthly basis to take into account the variability of needs between and within years. The concepts of Low-Water Target Flow (DOE) and shortage management are included in the SF structure with decision rules to represent how low-flow levels are managed within a year to limit water use. The time run is 20 years (data availability) but longer runs will be used for scenario analysis. The time step has been chosen not too large (0.25) to prevent large over and undershooting. Table 19 summarizes structural characteristics for the developed SD sub-model 1 in MAL4 with its SF structure being presented in Figure 30.

Table 19. Number of different variable types used in the SF structure of sub-model 1 for MAL4.

Characteristic	Variables	Stocks	Flows	Convertors	Constants	Equations	Lookups
Number	114	12	25	77	45	57	12

Variables in the water sub-model were summarized in COASTAL Deliverable D13 – Section 3.4.3 (Viaene et al., 2020) and some of them are also presented here in Table 20 with possibly some updates based on the sub-model progress in MAL4.

Table 20. Main variables in SD sub-model 1 for MAL4 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant) – The INTEG () function used in the Definition is for the integration of flows with time.

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Agricultural_land(t)	hectare	I	S	Surface agricultural land
Coastal_water_salinity_level(t)	Mcubicmeters	O	S	Coastal water salinity
dam_water_storage (t)	Mcubicmeters	L	S	Dams capacity
groundwater(t)	Mcubicmeters	L	S	Groundwater
population(t)	person	I	S	Total population

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reservoir_water_storage(t)	Mcubicmeters	L	S	Reservoir water storage for irrigation
surface_water(t)	Mcubicmeters	O	S	Surface water
Tourists(t)	Mcubicmeters	L	S	Tourists on vacation
Waste_water_treatment_plants(t)	person	I	S	Capacity Waste Water Treatment Plants
Water_in_marshes(t)	Mcubicmeters	L	S	Water stored in marshes
Water_in_soil(t)	Mcubicmeters	O	S	Soil water content
WaterStreams(t)	Mcubicmeters	O	S	Water stored in streams
Change_in_coastal_water_salinity	Mcubicmeters/Month	O	F	Changes in coastal salinity
decrease	hectare/Month	I	F	Decrease Agricultural land
Evapotranspiration	Mcubicmeters/Month	B	F	Evapotranspiration
Flow_2dams	Mcubicmeters/Month	O	F	Dams filling
Flow_4	Mcubicmeters/Month	O	F	Flow of soft water to the sea
Flow_to_stream	Mcubicmeters/Month	O	F	Flow from surface water to streams
Flow_to_WW_treatment_plants	Mcubicmeters/Month	O	F	Flow to waste water treatment plants
Flowing_through_stream	Mcubicmeters/Month	O	F	River flow
flows_from_WWTP	Mcubicmeters/Month	O	F	Discharge of waste water treatment plants
groundwater_recharge	Mcubicmeters/Month	O	F	Groundwater recharge
increase	hectare/Month	I	F	Increase Agricultural land
Infiltration	Mcubicmeters/Month	O	F	Infiltration
Interflow	Mcubicmeters/Month	O	F	Flow from soil to streams
outflows	Mcubicmeters/Month	O	F	Evaporation from dams
reservoirWateruse	Mcubicmeters/Month	O	F	Water from reservoirs used for irrigation
residential_population_net_growth	person/Month	I	F	Increase residential population
runoff	Mcubicmeters/Month	O	F	Runoff
tourist_arrival	person/Month	I	F	Arrival of tourists
tourist_departure	person/Month	O	F	Departure of tourists
water_release	Mcubicmeters/Month	O	F	Water release from dams
water_rise	Mcubicmeters/Month	O	F	Water rise
withdrawals_agr	Mcubicmeters/Month	I	F	Withdrawals from surface water for irrigating crops
withdrawals_agriculture	Mcubicmeters/Month	I	F	Withdrawals from groundwater for irrigating crops
withdrawals_domestic_use	Mcubicmeters/Month	I	F	Withdrawals from groundwater for domestic use
withdrawals_Wreserv	Mcubicmeters/Month	I	F	Withdrawals from ground water for filling reservois
"(mortality)_frequency_occurence"	Dmnl	I	A	Frequency of Oyster mortality
agricultural_water_demand	Mcubicmeters	I	A	Agricultural water demand for crops
Average_coastal_salinity	g/liter	O	A	Average coastal salinity

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average_time_to_st reams	days	I	A	Time needed for surface water to reach the streams
bassin_area_sqm	Square meters	B	C	River basin area
capacity_dam_stora ge	Mcubicmeters	O	A	Dam storage capacity
capacity_needed	Mcubicmeters	I	A	Reservoir capacity needed to respond to water needs
capacity_storage	Person (equivalent)	I	A	Capacity water reservoirs
capacity_WWTP	person/Month	I	F	Capacity waste water treatment plants
coastal_population _fraction_net_grow th	Mcubicmeters/ (person*Month)			Increase of costal population
comsumption_per_ capita	Mcubicmeter/(person *month)		A	Water consumption per capita
crops	hectare		A	Acreage with crops
dam_area_1	Square meters		C	Area of the dams

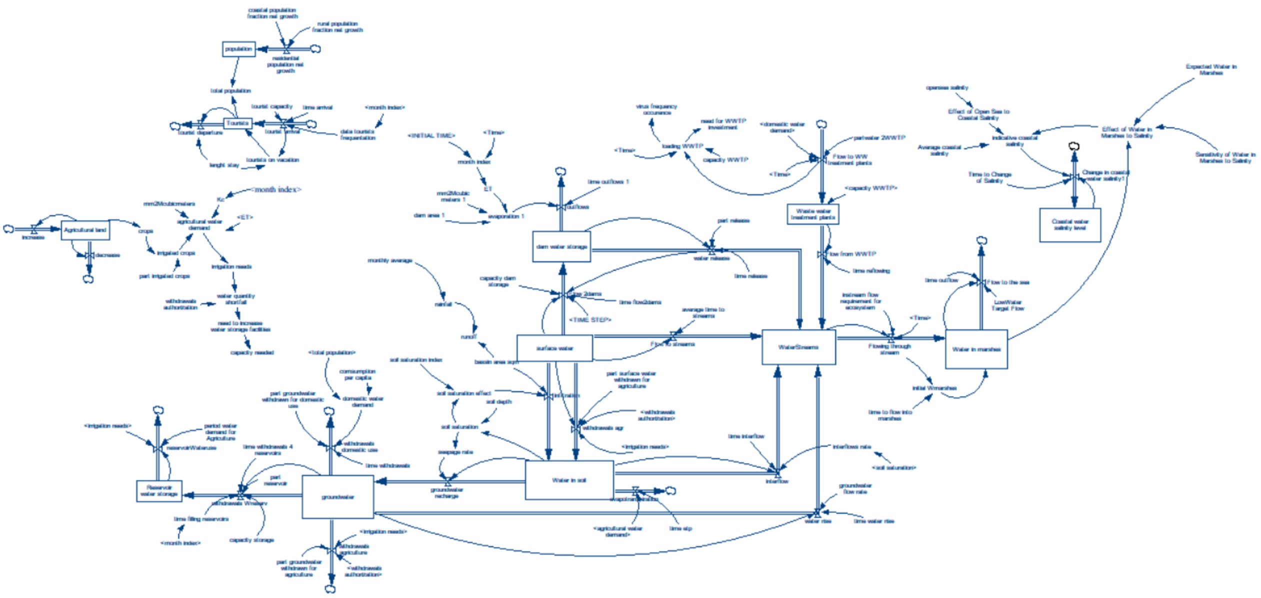

Figure 30. SF structure of SD sub-model 1 in MAL4 developed in Vensim software.

5.4.2.1.2 Outline of quantitative information to support sub-model 1

There are large amounts of data available on water flows, water quality, groundwater and surface water with varying time steps (Bichot et al., 2005 and 2013; EauFrance; EPTB; SAGE Charente; SAGE du bassin versant de la Charente; SIGES; BNPE). All the relevant data are included in the water sub-model and long time series of data will be helpful for calibrating this sub-model. For simulating scenarios and assessing the impact of changes in agriculture for concentrations of nitrates and pesticides in surface waters, we used results from previous studies (Vernier et al., 2016), as shown in Figure 31. These results on the scale of the Charente river basin will be used for supporting scenario analysis.

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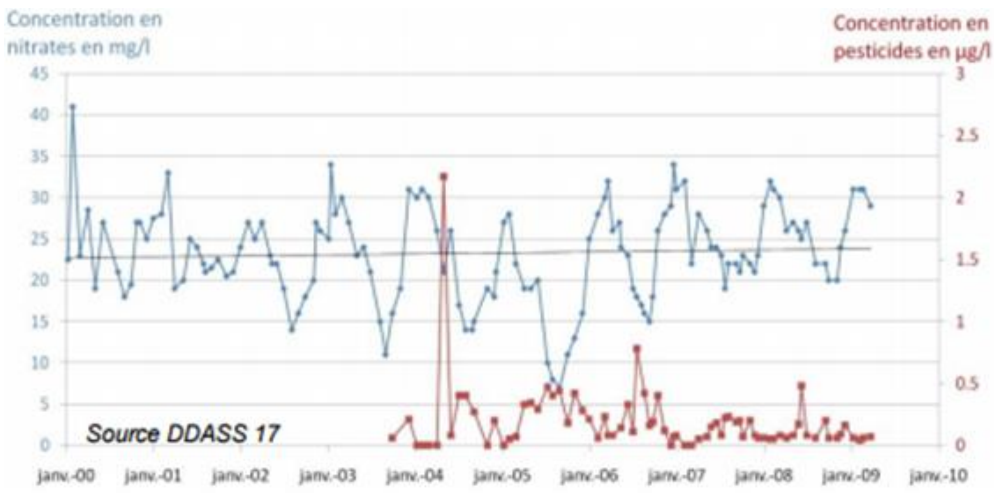

Figure 31. Trends in Nitrates (mg.l^{-1} -blue) and pesticides (μg.l^{-1} -red) concentrations in the Charente river (measured values in MAL4).

Table 21 provides an overview of equations/values used in the sub-model 1 to quantify some of the variables. The quantification of other variables is still in progress.

Table 21. Equations/Values used for quantification of SD sub-model 1 in MAL4.

Name	Equation/Value
Agricultural_land(t)	Agricultural_land(t-dt) + (increase - decrease)*dt
Coastal_water_salinity_level(t)	Coastal_water_salinity_level(t-dt) + (- Change_in_coastal_water_salinity)*dt
dam_water_storage(t)	dam_water_storage(t-dt) + (Flow_2dams - outflows - water_release)*dt
groundwater(t)	groundwater(t-dt) + (groundwater_recharge - withdrawals_Wreserv - withdrawals_domestic_use - water_rise - withdrawals_agriculture)*dt
population(t)	population(t-dt) + (residential_population_net_growth)*dt
reservoir_water_storage(t)	reservoir_water_storage(t-dt) + (withdrawals_Wreserv - reservoirWateruse)*dt
surface_water(t)	surface_water(t-dt) + (runoff - Infiltration - Flow_to_stream - Flow_2dams - withdrawals_agr)*dt
Tourists(t)	Tourists(t-dt) + (tourist_arrival - tourist_departure)*dt
Waste_water_treatment_plants(t)	Waste_water_treatment_plants(t-dt) + (Flow_to_WW_treatment_plants - flows_from_WWTP)*dt
Water_in_marshes(t)	Water_in_marshes(t-dt) + (Flowing_through_stream - Flow_4)*dt
Water_in_soil(t)	Water_in_soil(t-dt) + (Infiltration + withdrawals_agr - groundwater_recharge - Evapotranspiration - Interflow)*dt
WaterStreams(t)	WaterStreams(t-dt) + (Flow_to_stream + water_rise + Interflow + water_release + flows_from_WWTP - Flowing_through_stream)*dt
Change_in_coastal_water_salinity	(indicative_coastal_salinity-Coastal_water_salinity_level)/Time_to_Change_of_Salinity
decrease	0,001*Agricultural_land/TIME
Evapotranspiration	agricultural_water_demand/time_etp
Flow_2dams	MIN((capacity_dam_storage-surface_water)/DT;water_release)/time_flow2dams
Flow_4	MAX(Water_in_marshes/time_outflow; LowWater_Target_Flow)
Flow_to_stream	surface_water/average_time_to_streams
Flow_to_WW_treatment_plants	partwater_2WWTP*domestic_water_demand/TIME
Flowing_through_stream	MAX(WaterStreams/TIME; instream_flow_requirement_for_ecosystem/TIME)
flows_from_WWTP	Waste_water_treatment_plants/time_reflowing

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groundwater_recharge	seepage_rate*Water_in_soil
increase	0,002*Agricultural_land/TIME
Infiltration	(bassin_area_sqm*soil_saturation_effect)/TIME
Interflow	Water_in_soil*interflows_rate/time_interflow
outflows	evaporation_1/time_outflows_1
reservoirWateruse	MIN(((irrigation_needs/time_water_reuse)*period_water_demand_for_Agriculture); ((reservoir_water_storage/time_water_reuse)*period_water_demand_for_Agriculture))
residential_population_net_growth	(coastal_population_fraction_net_growth+rural_population_fraction_net_growth)
runoff	rainfall*bassin_area_sqm
tourist_arrival	tourist_capacity*data_tourists_frequentation/time_arrival
tourist_departure	Tourists/lenght_stay
water_release	dam_water_storage*part_release/time_release
water_rise	(groundwater_flow_rate*groundwater)/time_water_rise
withdrawals_agr	surface_water-MIN ((irrigation_needs/TIME); (withdrawals_authorization/TIME)*part_surface_water_withdrawn_for_agriculture)
withdrawals_agriculture	MIN(irrigation_needs; withdrawals_authorization)*part_groundwater_withdrawn_for_agriculture/TIME
withdrawals_domestic_use	(domestic_water_demand*part_groundwater_withdrawn_for_domestic_use)/time_withdrawals
withdrawals_Wreserv	MIN(part_reservoir*groundwater*time_filling_reservoirs/time_withdrawals_4_reservoirs; capacity_storage/time_withdrawals_4_reservoirs)
"(mortality)_frequency_occurence"	GRAPH(loading_WWTP) Points: (0,0000, 0,000), (0,131498, 0,614035), (0,253823, 1,35965), (0,370031, 2,45614), (0,501529, 3,77193), (0,636086, 5,000), (0,746177, 6,27193), (0,850153, 7,45614), (0,938838, 8,99123), (0,993884, 9,95614)
agricultural_water_demand	Data_Kc*ET*mm2Mcubicmeters*irrigated_crops
Average_coastal_salinity	30
average_time_to_streams	1
bassin_area_sqm	10550000000
capacity_dam_storage	12
capacity_needed	SMTH1(need_to_increase_water_storage_facilities; TIME)
capacity_storage	7
capacity_WWTP	200000
coastal_population_fraction_net_growth	0,0005
Consumption per capita	0,000054
crops	0,9*Agricultural_land
dam_area_1	325

5.4.2.2 Sub-model 2. Oyster farming

5.4.2.2.1 Quantified key land-sea interactions and feedback structures in sub-model 2

The key challenges to be addressed with sub-model 2 are to: (i) identify conditions of the maintenance and development of sustainable shellfish farming in the area; (ii) assess the impact of water quality on shellfish production (frequency of mortality, spat capture rate); and (iii) explore the impact of local market demand and coastal tourism development on local sales.

Dynamic assumptions are that: (i) deterioration on the environment will affect shellfish production and relocation to other zones outside the local coastal areas (other regions in Europe); and (ii) market external and local demand will drive the shellfish production. The coastal zone and in particular shellfish farming needs freshwater. 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 quantities of freshwater will affect the whole system based on this freshwater-saline water continuum. The mixture of freshwater 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 the use of coastal watersheds (Viaene et al., 2020). To highlight these interactions, the shellfish farming model intends to consider the production system throughout the development stages and its dependence on the environment regarding impact of virus frequencies on spat capture and water quality on oysters' mortality during their development phase. Production costs that determinate shellfish farmers' revenue are taken into account although these costs do not impact the volume of production and sales that are driven by the export and local market demand.

The SF structure for this sub-model focuses on the shellfish (namely oyster) production depending on phytoplankton concentration, the mortality rate due to poor quality water, and the sales greatly dependent of the market demand outside the case study area (export) and inside where sales are highly dependent of tourist visiting it. Direct and local sales imply limited transport costs with a relationship between sales and population densities on the coast. The increase of sanitary regulations entails additional costs for purification. The proximity of high population densities increases indeed the risk of viral pollution (with individual additional purification costs needed for export in case of viral contamination) and sometimes bans on sales (Viaene et al., 2020). All these variables have been taken into account in this sub model. Missing feedback loops will be possibly added after next round of stakeholders' workshops.

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 – quantified based on Figure 32), purchases and sales of shellfishes that increase or decrease the stocks (Viaene et al., 2020). The model does not take into account the relocation of oyster production outside the coastal zone at issue: indeed, oysters may be brought in or out of the stock of oyster for a given habitat (but not necessarily in or out of a business).

Links with agriculture sub-model rely on Nitrogen concentration in water and links with the water sub-model on the salinity and frequency of oyster mortality variables. Production relies on demand but also on water quality for growth, mortality and marketing authorization. Table 22 summarizes structural characteristics for the developed SD sub-model 2 in MAL4 with its SF structure being presented in Figure 33.

Table 22. Number of different variable types used in the SF structure of sub-model 2 for MAL4.

Characteristic	Variables	Stocks	Flows	Convertors	Constants	Equations	Lookups
Number	40	3	5	32	13	24	2

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Figure 32. Oyster mortality rate during a three-year growth period in the MAL4 coastal zone (Barbier et al., 2020).

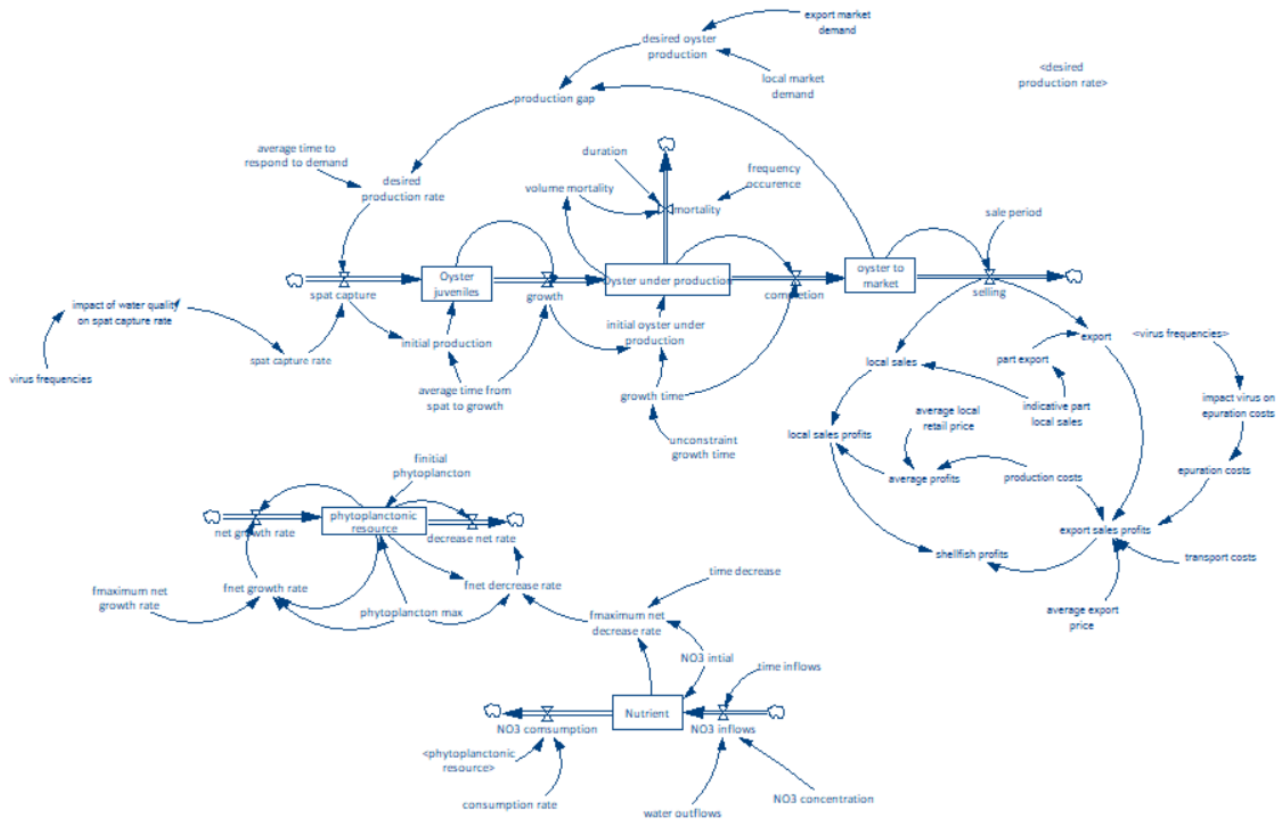

Figure 33. SF structure of SD sub-model 2 in MAL4 developed in Vensim software.

Variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.4.3 (Viaene et al., 2020) and some of them are also presented here in Table 23 with possibly some updates based on the sub-model progress in MAL4.

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Table 23. Main variables in SD sub-model 2 for MAL4 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Oyster_juveniles(t)	ton	I	S	Stock of oyster after the first year of growth
oyster_to_market(t)	ton	I	S	Stock of oyster ready for the market (after three year of growth)
Oyster_under_production(t)	ton	I	S	Stock of oyster under production (2 years old)
completion	ton/year	I	F	Passing from 2-year old oyster to last period of growth
growth	ton/year	I	F	Passing from the juvenile stage (1 year) to oyster development stage
mortality	ton/year	L	F	Oyster mortality during the growth process (year 2)
selling	ton/year	O	F	Sales
spat_capture	ton/year	L	F	Capture of spat
average_export_price	euros/ton	D	A	Average export price
average_local_retail_price	euros/ton	D	A	Average local price
average_profits	euros/ton	O	A	Average profits from oyster sales
average_time_from_spat_to_growth	year	L	C	Average time to grow from spat to marketable oyster
average_time_to_respond_to_demand	year	L	A	Average time to respond to oyster demand
desired_oyster_production	ton	D	A	Oyster production target
desired_production_rate	ton/year	D	F	Oyster production rate to reach the target
duration	year	L		Duration mortality period
epuration_costs	euros/ton	I	A	cleansing costs
export	ton/year	O	A	Quantity of oyster exported
export_market_demand	ton	D	A	Demand of oyster for export
export_sales_profits	euros/year	O	A	Profits from export
frequency_occurence	year	B	A	Frequency of oyster mortality
growth_time	year	L	A	Growth time from juvenile to oyster ready to be marketed

5.4.2.2.2 Outline of quantitative information to support sub-model 2

Many technical reports or scientific studies on the shellfish farming sector within the case study area are available. These data are used for quantification of the sub-model 2 (Barbier et al., 2020; Dimitri, 2016; Flash Info Maline Ifremer, 2018) and will support the calibration process. Table 24 provides an overview of equations/values used in the sub-model 2 to quantify variables.

Table 24. Equations/Values used for quantification of SD sub-model 2 in MAL4.

Name	Equation/Value
Oyster_juveniles(t)	Oyster_juveniles(t-dt) + (spat_capture - growth)*dt
oyster_to_market(t)	oyster_to_market(t-dt) + (completion - selling)*dt
Oyster_under_production(t)	Oyster_under_production(t-dt) + (growth - completion - mortality)*dt
completion	Oyster_under_production/growth_time

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growth	Oyster_juveniles/average_time_from_spat_to_growth
mortality	volume_mortality/duration*(IF TIME >= (5) AND TIME <= (50) AND (TIME - (5)) MOD (frequency_occurence) < (duration) THEN 1 ELSE 0)
selling	(oyster_to_market/sale_period)
spat_capture	desired_production_rate*spat_capture_rate
average_epuration_costs	400
average_export_price	7000
average_local_retail_price	3700
average_profits	average_local_retail_price-production_costs
average_time_from_spat_to_growth	1
average_time_to_respond_to_demand	1
desired_oyster_production	local_market_demand+STEP(0,1*local_market_demand; 8)+export_market_demand+STEP(0,2*export_market_demand; 5)
desired_production_rate	production_gap/average_time_to_respond_to_demand
duration	1
epuration_costs	impact_virus_on_epuration_costs*average_epuration_costs
export	part_export*selling
export_market_demand	10000
export_sales_profits	export*(average_export_price-(production_costs+transport_costs+epuration_costs))
frequency_occurence	3
growth_time	unconstraint_growth_time
impact_of_water_quality_on_spat_capture_rate	GRAPH(virus_frequencies) Points: (0,000, 1,000), (0,166666666667, 0,978627597813), (0,333333333333, 0,935220909442), (0,500, 0,850849378108), (0,666666666667, 0,732), (0,833333333333, 0,575), (1,000, 0,408)
impact_virus_on_epuration_costs	GRAPH(virus_frequencies) Points: (0,000, 0,000), (0,100, 0,0612070245601), (0,200, 0,128851248086), (0,300, 0,203609676702), (0,400, 0,28623051789), (0,500, 0,377540668798), (0,600, 0,478453992107), (0,700, 0,589980462274), (0,800, 0,713236273698), (0,900, 0,849455011967), (1,000, 1,000)
indicative_part_local_sales	0,8
initial_oyster_under_production	growth*growth_time
initial_production	average_time_from_spat_to_growth*spat_capture
local_market_demand	50000
local_sales	indicative_part_local_sales*selling
local_sales_profits	local_sales*average_profits
part_export	1- (indicative_part_local_sales)
production_costs	3000
production_gap	desired_oyster_production-oyster_to_market
sale_period	1
Shellfish_profits	local_sales_profits+export_sales_profits
spat_capture_rate	0,8*impact_of_water_quality_on_spat_capture_rate
transport_costs	720
unconstraint_growth_time	3
virus_frequencies	RANDOM(0,1; 0,5)
volume_mortality	0,05*Oyster_under_production
Oyster_juveniles(t)	Oyster_juveniles(t-dt) + (spat_capture - growth)*dt
oyster_to_market(t)	oyster_to_market(t-dt) + (completion - selling)*dt
Oyster_under_production(t)	Oyster_under_production(t-dt) + (growth - completion - mortality)*dt
completion	Oyster_under_production/growth_time
growth	Oyster_juveniles/average_time_from_spat_to_growth
mortality	volume_mortality/duration*(IF TIME >= (5) AND TIME <= (50) AND (TIME - (5)) MOD (frequency_occurence) < (duration) THEN 1 ELSE 0)
selling	(oyster_to_market/sale_period)
spat_capture	desired_production_rate*spat_capture_rate

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average_export_price	7000
average_local_retail_price	3700
average_profits	average_local_retail_price-production_costs
average_time_from_spat_to_growth	1
average_time_to_respond_to_demand	1
desired_oyster_production	local_market_demand+STEP(0,1*local_market_demand; 8)+export_market_demand+STEP(0,2*export_market_demand; 5)
desired_production_rate	production_gap/average_time_to_respond_to_demand
duration	1
epuration_costs	400*impact_virus_on_epuration_costs
export	part_export*selling
export_market_demand	10000
export_sales_profits	export*(average_export_price-(production_costs+transport_costs+epuration_costs))
frequency_occurence	3
growth_time	unconstraint_growth_time
impact_of_water_quality_on_spat_capture_rate	GRAPH (virus_frequencies) Points: (0,000, 1,000), (0,166666666667, 0,978627597813), (0,333333333333, 0,935220909442), (0,500, 0,850849378108), (0,666666666667, 0,732), (0,833333333333, 0,575), (1,000, 0,408)
impact_virus_on_epuration_costs	GRAPH(virus_frequencies) Points: (0,000, 0,000), (0,100, 0,0612070245601), (0,200, 0,128851248086), (0,300, 0,203609676702), (0,400, 0,28623051789), (0,500, 0,377540668798), (0,600, 0,478453992107), (0,700, 0,589980462274), (0,800, 0,713236273698), (0,900, 0,849455011967), (1,000, 1,000)
indicative_part_local_sales	0,8
initial_oyster_under_production	growth*growth_time
initial_production	average_time_from_spat_to_growth*spat_capture
local_market_demand	50000
local_sales	indicative_part_local_sales*selling
local_sales_profits	local_sales*average_profits
part_export	1- (indicative_part_local_sales)
production_costs	3000
production_gap	desired_oyster_production-oyster_to_market
sale_period	1
Shellfish_profits	local_sales_profits+export_sales_profits
spat_capture_rate	0.8*impact_of_water_quality_on_spat_capture_rate
transport_costs	720
unconstraint_growth_time	3
virus_frequencies	RANDOM(0,1; 0,5)
volume_mortality	0.05*Oyster_under_production

5.4.2.3 Sub-model 3. Agriculture

5.4.2.3.1 Quantified key land-sea interactions and feedback structures in sub-model 3

The key challenges to be addressed with sub-model 3 are: (i) the evolution of agriculture and the development of sustainable farming systems with diversification of crops; (ii) the development of organic farming and opportunities for new (short) supply chains; (iii) the limitation of irrigated crops and its consequences on land-use, changes of crop rotations, water availability, water quality, infrastructure development and port activities; and (iv) the impact of an increase in reservoirs capacity on water resources, on crops diversification and on irrigated crops.

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Dynamic hypothesis we made are: (i) pressure from public policies (regulations on pesticides, nitrates, etc.) and increasing demand for organic products will foster the development of organic and sustainable farming instead of intensive conventional crops; (ii) increasing regulations on irrigation (quotas, tariffs) will redirect productions that benefit the most from water; and (iii) population and economic activities in rural areas will develop. The objective of the agriculture sub-model is then to quantify the impact of agricultural system changes on crops diversification, on irrigated crops, and on water quality (Viaene et al., 2020). This conversion towards a more sustainable agriculture will most likely affect land availability with an increasing need for agricultural land (because extensive farming requires more land to maintain farmers' income). It will cause also the adaption of the economic sectors (new infrastructure needed to ensure the storage of organic production, development of new short supply chains). Amongst sustainable farming systems, organic farming systems provide more employment, need more space per unit of production, and are more likely to generate local supply chains.

Nitrogen 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 affect water quality and aquatic biodiversity (Viaene et al., 2020). The risk of eutrophication, however, is limited for this case study thanks to the high turbidity of coastal waters. Nitrate fluxes to coastal waters may play, however, a favorable role for oyster growth.

Table 25 summarizes structural characteristics for the developed SD sub-model 3 in MAL4 with its SF structure being presented in Figure 34. Variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.4.3 (Viaene et al., 2020) and are also presented here in Table 26 with possibly some updates based on the sub-model progress in MAL4.

Table 25. Number of different variable types used in the SF structure of sub-model 3 for MAL4.

Characteristic	Variables	Stocks	Flows	Convertors	Constants	Equations	Lookups
Number	87	7	10	70	33	47	5

Table 26. Main variables in SD sub-model 3 for MAL4 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant)

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Building_storage_facilities(t)	ton	I/O	S	Storage facilities under construction
Conventional_field_crop_area(t)	hectare	I	S	Agricultural area under conventional farming systems
new_vineyard(t)	hectare	O	S	New vineyard plantation
organic_farming_area(t)	hectare	I/O	S	Acreage under organic farming systems
Organic_storage_facilities(t)	ton	O	S	Storage facility for agricultural organic products
transition_field_croparea(t)	hectare	O	S	Conventional agricultural acreage turning to organic farming
vineyard_under_production(t)	hectare	I/O	S	Vineyard area in production
Agricultural_land_abandonment	hectare/year	O	F	Agricultural areas abandoning agriculture
completing_storage_facilities	ton/year	O	F	Storage facilities to be completed

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farming_system_change	hectare/year	O	F	Shift from conventional to organic farming
"grubbing-up"	hectare/year	I	F	areas planted with vines that is grubbed-up
increasing_agricultural_land	hectare/year	I	F	Increase in agricultural land
Organic_abandonment	hectare/year	O	F	Abandoning agriculture
production	ton/hectare	O	A	
shift_to_Organic_farming	hectare/year	O	F	Changing to organic farming
starting_building_storage	ton/year	I	F	
vine_planting_rate	hectare/year	I	F	Rate of vine planting
abandonment_rate	Dmnl	I	F	
agricultural_water_demand	Mm3	O	A	Overall agricultural water demand
authorized_production_per_surface_vineyard	Hl/hectare	I	A	Authorized Cognac production per hectare
av_production_per_ha	Hl/hectare	I	A	Average Cognac production per hectare
average_conventional_yield	ton/hectare	I	A	Average production
average_irrigation_needs	Mm3/hectare	I	A	Average irrigation need for irrigated crops (except vineyards)
average_Nfertilizers_use	Kg/hectare	I	A	Average use of Nitrogen in conventional agriculture
average_organic_grains_yield	ton/hectare	I	A	Average production of cereals in organic farming
average_Organic_Nfertilzers_use	Kg/hectare	I	A	Average use of Nitrogen fertilizers in organic farming
average_summer_temperatures	Celsius degree	I	A	Average summer temperatures
average_time_to_full_production	year	I	C	Time for new vines to reach full production
building_storage	ton	I	A	
cereal_share	Dmnl	I	A	Part of cereals in conventional production systems
cereals_area	hectare	I/O	A	Acreage in cereals in conventional farming system
changing_part	Dmnl	I	A	Part of conventional agricultural systems changing to organic
Cognac_production	Hl	O	A	Overall Cognac production
demand_for_organic_products	ton	D	A	Consumer demand for organic products
desired_Cognac_production	Hl	D	A	Cognac production target
desired_production_rate	Hl/year	I	A	Rate of plantation to
effect_climate_change_on_summer_temperatures	Dmnl	D	A	Effect of climate change on air temperature
effect_of_change_on_Nloads	Dmnl	O	A	Impact of changing farming system on nitrogen loads
effect_of_demand_on_organic_prices	Dmnl	O	A	Effect of demand for organic products on their prices

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effect_of_Gross_Margin_on_farming_system_changes	Dmnl	I	A	Effect of difference in gross margin between organic and conventional on changing farming systems
Fertilizers_use	Kg	I	A	Nitrogen fertilizers used in conventional farming
Fertilizers_used_in_organic_farming	Kg	I	A	Nitrogen fertilizers used in organic farming
grassland	hectare	I/O	A	Grassland area
impact_prices_on_crops_rotation	Dmnl	I	A	Impact of the difference in price between cereals and maize on rotation
increasing_rate	Dmnl	I	C	Rate of increase agricultural land under conventional farming
indicative_organic_prices	euros/ton	I	A	reference price of organic products
indicative_share	Dmnl	I	A	Reference share of cereals in conventional farming
initial_conventional_field_crop_area	hectare	I	A	Acreage of crops in conventional farming at the start of simulation
initial_new_vineyard	hectare	I	A	Acreage of new vineyard at the start of the simulation
initial_Organic_area	hectare	I	A	Acreage under organic framing at the start of the simulation
initial_vineyard_area	hectare	I	A	Acreage of vineyard in production at the start of the simulation
irrigated_Conventional_crops	hectare	I/O	A	Acreage of irrigated crops under conventional farming
irrigated_mais	hectare	I/O	A	Acreage of maize under conventional farming
irrigated_other_crops	hectare	I/O	A	Crops (except maize) irrigated
irrigated_vineyards	hectare	I/O	A	Vine irrigated
maize_area	hectare	I/O	A	Area with maize
maize_share	Dmnl	I/O	A	Part of maize in agricultural production under conventional farming system
market_demand	Hl	D	A	Cognac Market demand
need_for_Organic_storage_facilities	ton	O	A	Need of storage for organic products
Organic_cereals	hectare	I/O	A	Area with cereals under organic farming
Organic_irrigated	hectare	I/O	A	Area with irrigated crops under organic farming
Organic_new_crops	hectare	I/O	A	New crops under organic farming (crop diversification)
other_crops	hectare	I/O	A	New crops (except cereals and maize)
planting_rights	Dmnl	I	C	Planting rights for Cognac Vineyard
price_cereals	euros/ton	I	A	Price of cereals under conventional farming
price_conventional_grains	euros/ton	I	A	Price cereals under conventional farming practices
price_maize	euros/ton	I	A	Price maize (conventional)
price_organic_grains	euros/ton	I	A	Price cereals under Organic farming practices
production_gap	Hl	O	A	Difference between production and market demand

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production_of_organic_products	tons	O	A	Overall production of organic products
relative_part_of_irrigated_vineyards	Dmnl	I	A	Relative part of irrigated vineyards
relative_price_between_conventional_and_Organic_crops	Dmnl	I/O	A	Relative price between products from conventional and organic farming systems
relative_yield_between_Organic_and_Conventional_products	Dmnl	I/O	A	Relative yield between products from conventional and organic farming systems
replacement_rate	Dmnl	I	A	Rate of vine replacement
share_irrigated_maize	Dmnl	I	A	Share of irrigated maize area under conventional farming
share_irrigated_other_crops	Dmnl	I	A	Share of irrigated crops (except maize) under conventional farming
share_Organic_irrigated	Dmnl	I	A	Share of irrigated maize area under organic farming area
storage_gap	ton	O	A	Gap between storage facilities and needs for storage
summer_temperatures	Celsius degree	I	A	Summer temperatures
time_for_transition	year	I	C	Time required to shift from conventional to Organic farming system
time_to_build	year	I	C	Time needed to build storage facilities
time_to_plan	year	I	C	Time for planning storage building
time_to_respond_to_demand	year	I	A	
vineyard_extension	hectare/year	I	A	Authorized vineyard extension
vineyard_water_demand	Mm3	I/O	A	Water demand of the overall vineyard
vineyard_water_needs	Mm3/hectare	I/O	A	Vineyard water needs

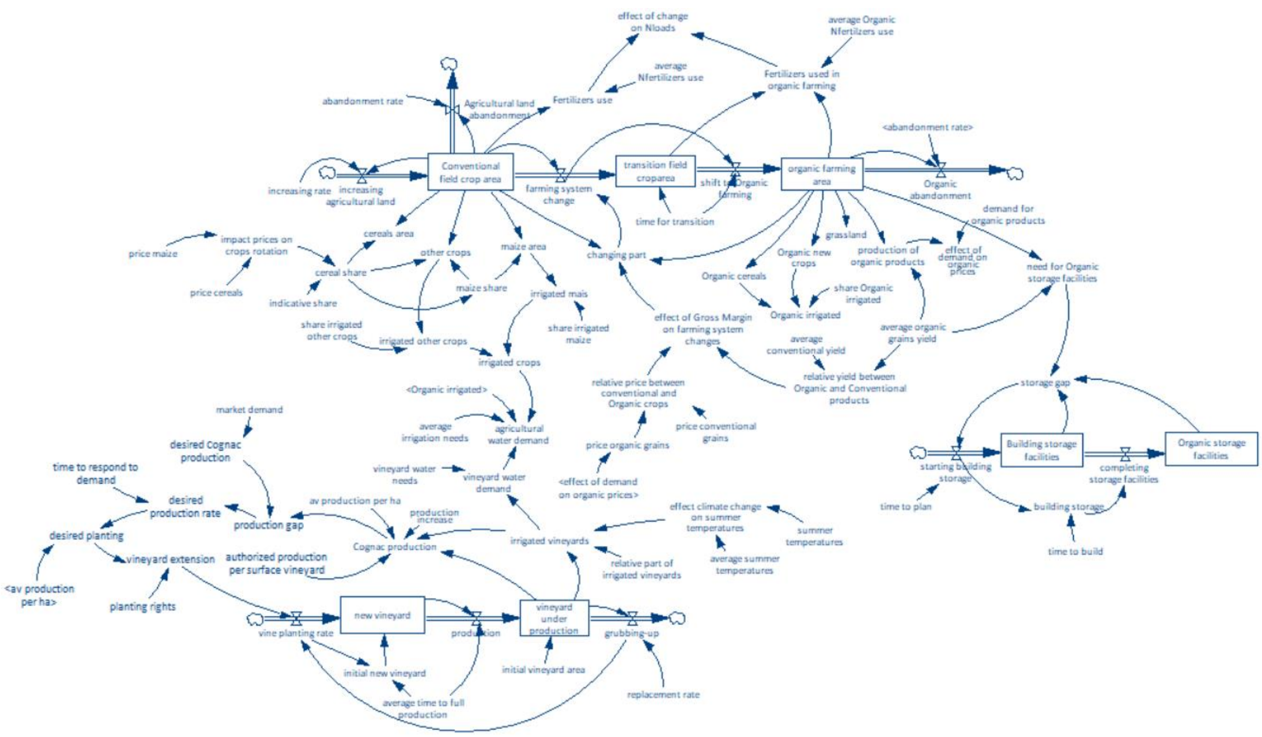

Figure 34. SF structure of SD sub-model 3 in MAL4 developed in Vensim software.

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5.4.2.3.2 Outline of quantitative information to support sub-model 3

On the Charente watershed, INRAE carried out previous studies to assess the impact of farming system changes on Nitrogen and pesticides use (Barberis, 2015). The changes were assessed in terms of impact indicators (Nitrogen, pesticides), and concentrations and flows were simulated (using the SWAT model) in the basin's outflow (Figure 35). These results will be used for quantification when necessary. All needed information regarding markets of agricultural products have also been used (Agreste; Oracle; Observatoire Régional de l'Agriculture Biologique, 2017; French Ministry of Agriculture).

Table 27 provides an overview of equations/values used in the sub-model 3 to quantify variables.

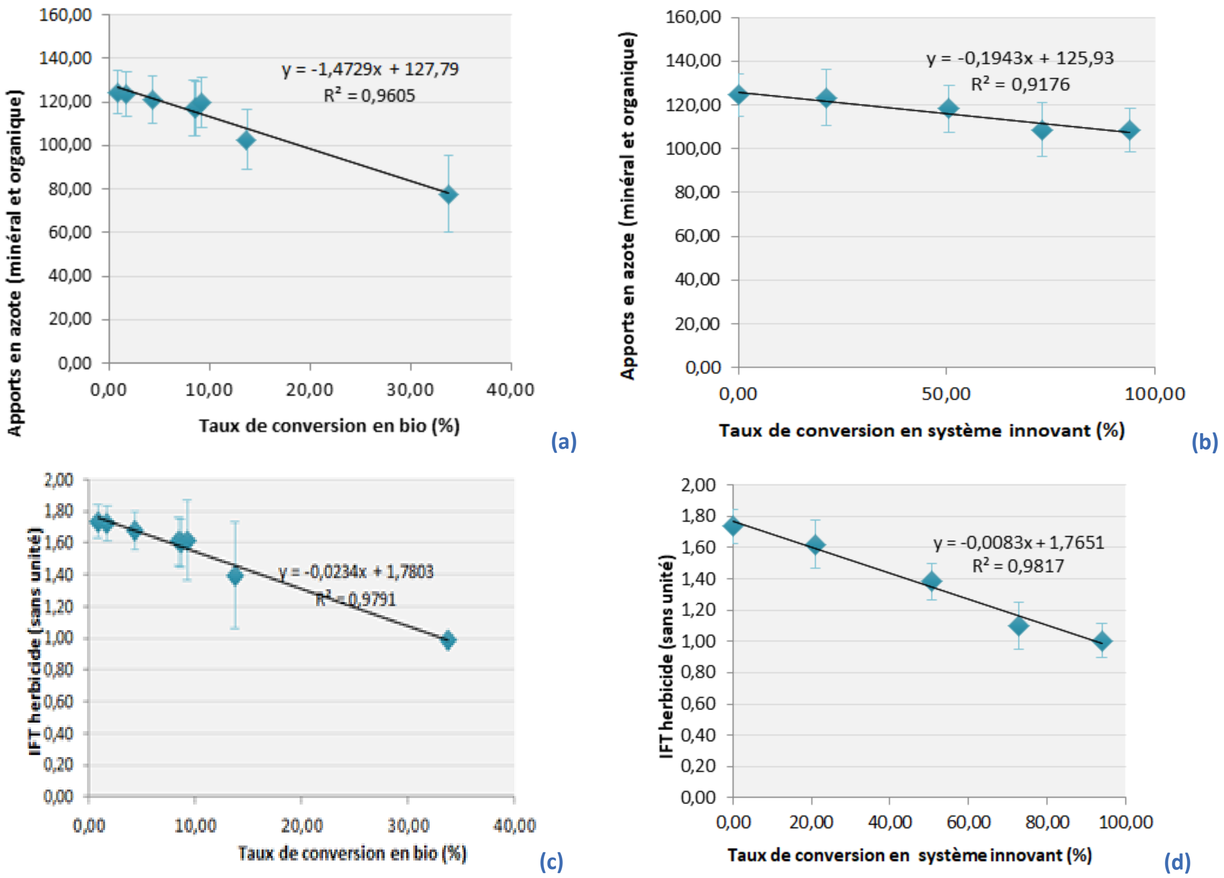

Figure 35. Farming system changes from conventional to organic (Bio) (a) and sustainable systems (système innovant) (b). Associated reduction of treatment frequency index (IFT) for herbicides under the organic (Bio) (c) and sustainable systems (système innovant) (d).

Table 27. Equations/Values used for quantification of SD sub-model 3 in MAL4.

Name	Equation/Value
Building_storage_facilities(t)	Building_storage_facilities(t-dt) + (starting_building_storage - completing_storage_facilities)*dt
Conventional_field_crop_area(t)	Conventional_field_crop_area(t-dt) + (increasing_agricultural_land - Agricultural_land_abandonment - farming_system_change)*dt
new_vineyard(t)	new_vineyard(t-dt) + (vine_planting_rate - production)*dt
organic_farming_area(t)	organic_farming_area(t-dt) + (shift_to_Organic_farming - Organic_abandonment)*dt
Organic_storage_facilities(t)	Organic_storage_facilities(t-dt) + (completing_storage_facilities)*dt
transition_field_croparea(t)	transition_field_croparea(t-dt) + (farming_system_change - shift_to_Organic_farming)*dt
vineyard_under_production(t)	vineyard_under_production(t-dt) + (production - "grubbing-up")*dt

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Agricultural_land_abandonment	(abandonment_rate*Conventional_field_crop_area)
completing_storage_facilities	building_storage
farming_system_change	(Conventional_field_crop_area*changing_part)
"grubbing-up"	replacement_rate*vineyard_under_production
increasing_agricultural_land	(increasing_rate*Conventional_field_crop_area)
Organic_abandonment	(organic_farming_area*abandonment_rate)
production	new_vineyard/average_time_to_full_production
shift_to_Organic_farming	DELAY(farming_system_change; time_for_transition; farming_system_change)
starting_building_storage	storage_gap*time_to_plan
vine_planting_rate	"grubbing-up"+vineyard_extension
abandonment_rate	0,03
agricultural_water_demand	(irrigated_Conventional_crops+Organic_irrigated)*average_irrigation_needs+vineyard_water_demand
authorized_production_per_surface_vineyard	14
av_production_per_ha	11
average_conventional_yield	7
average_irrigation_needs	4000*0.000001
average_Nfertilizers_use	1.5
average_organic_grains_yield	3
average_Organic_Nfertilzers_use	120
average_summer_temperatures	28
average_time_to_full_production	7
building_storage	starting_building_storage*time_to_build
cereal_share	impact_prices_on_crops_rotation*indicative_share
cereals_area	cereal_share*Conventional_field_crop_area
changing_part	(organic_farming_area/Conventional_field_crop_area)*effect_of_Gross_Margin_on_farming_system_changes
Cognac_production	MAX((vineyard_under_production-irrigated_vineyards*av_production_per_ha+irrigated_vineyards*av_production_per_ha*production_increase); (authorized_production_per_surface_vineyard))
demand_for_organic_products	10000
desired_Cognac_production	market_demand+STEP(0,02*market_demand; 1)
desired_production_rate	production_gap/time_to_respond_to_demand
effect_climate_change_on_summer_temperatures	GRAPH(summer_temperatures/average_summer_temperatures) Points: (0,030581, 0,0526316), (0,489297, 0,0657895), (1,20795, 0,0745614), (1,85015, 0,105263), (2,49235, 0,149123), (2,84404, 0,179825), (3,28746, 0,210526), (3,83792, 0,2500), (4,41896, 0,298246), (4,93884, 0,350877)
effect_of_change_on_Nloads	GRAPH(Fertilizers_used_in_organic_farming/Fertilizers_use) Points: (1,01223, 0,0131578), (1,26911, 0,350877), (1,4893, 0,592105), (1,7156, 0,899123), (2,11315, 1,57895), (2,41284, 2,19298), (2,75535, 3,44298), (2,98777, 4,95614)
effect_of_demand_on_organic_prices	GRAPH(production_of_organic_products/demand_for_organic_products) Points: (0,020, 1,79464571926), (0,1125, 1,79005467932), (0,205, 1,78161810407), (0,2975, 1,76632981767), (0,390, 1,73931345598), (0,4825, 1,69362860784), (0,575, 1,62183988894), (0,6675, 1,52108389173), (0,760, 1,4000), (0,8525, 1,27891610827), (0,945, 1,17816011106), (1,0375, 1,10637139216), (1,130, 1,06068654402), (1,2225, 1,03367018233), (1,315, 1,01838189593), (1,4075, 1,00994532068), (1,500, 1,00535428074)
effect_of_Gross_Margin_on_farming_system_changes	GRAPH(relative_yield_between_Organic_and_Conventional_products*relative_price_between_conventional_and_Organic_crops) Points: (1,000, 0,0154061015037), (1,150, 0,0266003956478), (1,300, 0,0557818153151), (1,450, 0,126929238758), (1,600,

	0,275354237979), (1,750, 0,50438598), (1,900, 0,733417722021), (2,050, 0,881842721242), (2,200, 0,952990144685), (2,350, 0,982171564352), (2,500, 0,993365858496)
Fertilizers_use	Conventional_field_crop_area*average_Nfertilizers_use
Fertilizers_used_in_organic_farming	average_Organic_Nfertilzers_use*(transition_field_croparea+organic_farming_area)
grassland	0,3*organic_farming_area
impact_prices_on_crops_rotation	GRAPH(price_cereals/price_maize) Points: (0,000, 0,0000), (0,66055, 0,135965), (0,842508, 0,2500), (1,09939, 0,381579), (1,40979, 0,5000), (1,81651, 0,618421), (2,24465, 0,72807), (2,7156, 0,811404), (3,15443, 0,877193), (3,51835, 0,934211), (3,9893, 0,995614)
increasing_rate	0
indicative_organic_prices	240
indicative_share	0,6
initial_conventional_field_crop_area	650000
initial_new_vineyard	average_time_to_full_production*vine_planting_rate
initial_Organic_area	14000
initial_vineyard_area	78000
irrigated_Conventional_crops	MAX(irrigated_mais+irrigated_other_crops; 0)
irrigated_mais	MAX(share_irrigated_maize*maize_area; 0)
irrigated_other_crops	MAX(share_irrigated_other_crops*other_crops; 0)
irrigated_vineyards	vineyard_under_production*relative_part_of_irrigated_vineyards*effect_climate_change_on_summer_temperatures
maize_area	maize_share*Conventional_field_crop_area
maize_share	1-cereal_share
market_demand	1,00E+06
need_for_Organic_storage_facilities	average_organic_grains_yield*organic_farming_area
Organic_cereals	0,4*organic_farming_area
Organic_irrigated	(Organic_new_crops+Organic_cereals)*share_Organic_irrigated
Organic_new_crops	0,3*organic_farming_area
other_crops	(1-maize_share+cereal_share)*Conventional_field_crop_area
planting_rights	1
price_cereals	180
price_conventional_grains	150
price_maize	160
price_organic_grains	indicative_organic_prices*effect_of_demand_on_organic_prices
production_gap	desired_Cognac_production-Cognac_production
production_increase	2
production_of_organic_products	average_organic_grains_yield*organic_farming_area
relative_part_of_irrigated_vineyards	0,01
relative_price_between_conventional_and_Organic_crops	price_organic_grains/price_conventional_grains
relative_yield_between_Organic_and_Conventional_products	average_organic_grains_yield/ average_conventional_yield
replacement_rate	0,04
share_irrigated_maize	0,4
share_irrigated_other_crops	0,2
share_Organic_irrigated	0,2
storage_gap	need_for_Organic_storage_facilities-(Organic_storage_facilities+Building_storage_facilities)
summer_temperatures	NORMAL(35; 5; 0; 28; 40)
time_for_transition	2
time_to_build	2
time_to_plan	1
time_to_respond_to_demand	4
vineyard_extension	MAX(desired_production_rate/av_production_per_ha; planting_rights)

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vineyard_water_demand	irrigated_vineyards*vineyard_water_needs
vineyard_water_needs	700*0.000001

5.4.2.4 Sub-model 4. Infrastructure (Dikes)

5.4.2.4.1 Quantified key land-sea interactions and feedback structures in sub-model 4

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 terms. Sea level rise may affect coastal population, calling for long-term planning and solutions. Risk of sea level rise requires the enhancement of dikes in populated flat coastal areas and a better dimension of structures in the coastal zone (i.e. rising of port platforms to required elevation - Port Atlantique). With its 450 km of coastline, the coastal zone of the MAL4 is particularly vulnerable to strong storms and the objective is to protect the coast from weather events (+20cm flood level). The coastal protection reinforcement plan, 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 addition, a part of the agricultural land in marshes may probably need to be abandoned because of this rise resulting in increased salinization of the soils (Viaene et al., 2020).

The SF structure is based on the dynamic Hypotheses as perceived risk of flooding will increase pressure to expand dikes leading to dike construction. Considering that development of infrastructure takes time, we have explicitly added stocks ‘under construction’ precursors, as this will facilitate reproducing the dynamics of the infrastructure development process. Table 28 summarizes structural characteristics for the developed SD sub-model 4 in MAL4 with its SF structure being presented in Figure 36. Variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.4.3 (Viaene et al., 2020) and are also presented here in Table 29 with possibly some updates based on the sub-model progress in MAL4.

Table 28. Number of different variable types used in the SF structure of sub-model 4 for MAL4.

Characteristic	Variables	Stocks	Flows	Convertors	Constants	Equations	Lookups
Number	26	2	2	22	8	16	3

Table 29. Main variables in SD sub-model 4 for MAL4 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant)

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Dikes(t)	km	I	S	Embankments length
dikes_under_construction(t)	km	O	S	Dike being built
completing_dikes	km/Year	O	F	Dike construction per year
starting_dike_construction	km/Year	I	F	Dike construction at the start
acceptable_risk	1/Year	I	A	Flooding risk acceptable
Agricultural_coastal_land	Hectare	I	A	Agricultural areas in the coastal zone
average_dike_demand	km	I	A	Demand for building dike
building_dikes	km/Year	O	A	Building of dikes
coastal_land_abandonment	Hectare	I	A	Agricultural coastal land agreed to be abandoned to the sea
construction_effect_on_dikes_available	Dmnl	I	A	Effect of construction on embankments

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dike_gap	km	I/O	A	Gap between demand in dikes and existing embankment
Dikes_available	km	I	A	New dike constructed
effect_of_risk_of_floodings_on_coastal_farmland_abandonment	Dmnl	I	A	Effect of risk of flooding on coastal farmland abandonment
forecast_of_dikes_construction	km	I	A	Dike construction foreseen
fraction_land_at_risk	Dml	I	A	Actual fraction of the coastal land at risk of flooding
indicating_dikes	km	I	A	
normal_land_fraction_at_risk	Dml	O	A	Coastal land considered at risk of flooding
perceived_risk	Hectare/km	I	A	Perceived risk of flooding by the population
planned_dike	Km	I/O	A	Embankment planned
pressure_to_expand_dikes	Dml	I	A	Popular pressure to expand existing dikes
risk_of_floodings	Hectare/km	I	A	Risk of flooding
time_to_build_dikes	Year	I	A	Time needed to build dikes
time_to_demand	Year	I	A	Time to decide construction following population's demand
time_to_perceive_risk	Year	I	A	Time for population to perceive risk
time_to_plan_dikes	Year	I	A	Time needed to start dikes building
weight_on_forecast	Dml	I	A	Weight on the planning

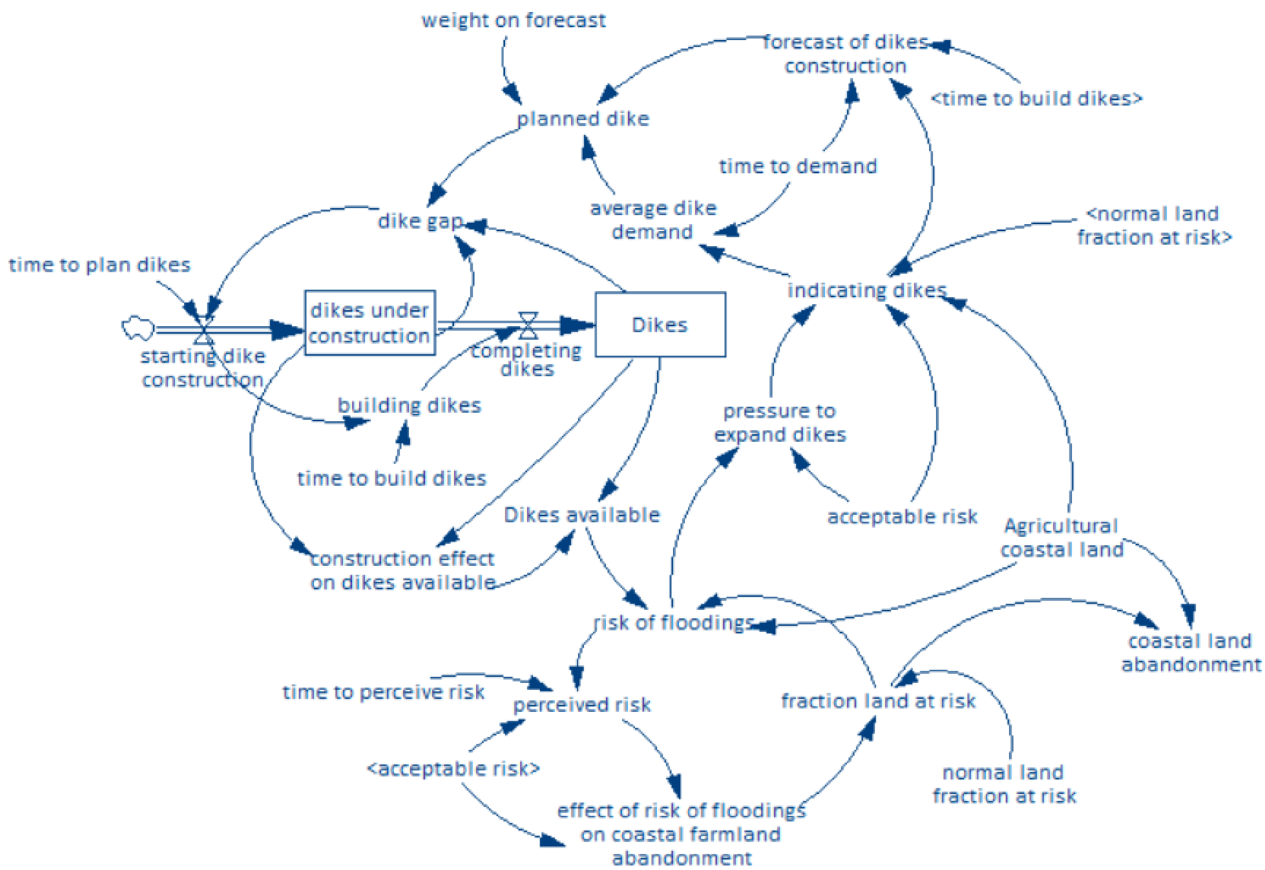

Figure 36. SF structure of SD sub-model 4 in MAL4 developed in Vensim software.

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5.4.2.4.2 Outline of quantitative information to support sub-model 4

In this sub-model, we considered two stocks: the embankments under construction (to take into account the construction period) and the embankments built. We considered different types of risk (the risk in term of likelihood of flooding, the risk perceived by the population and the risk accepted). The perceived risk is likely to lead population to ask for dike construction that will decrease the risk of flooding. A part of the coastal land at risk consists in agricultural land that may be abandoned to marine submersion. Table 30 provides an overview of equations/values used in the sub-model 4 to quantify variables.

Table 30. Equations/Values used for quantification of SD sub-model 4 in MAL4.

Name	Equation/Value
Dikes(t)	Dikes(t-dt) + (completing_dikes)*dt
dikes_under_construction(t)	dikes_under_construction(t-dt) + (starting_dike_construction - completing_dikes)*dt
completing_dikes	building_dikes
starting_dike_construction	dike_gap/time_to_plan_dikes
acceptable_risk	1/50
Agricultural_coastal_land	48200
average_dike_demand	SMTH1(indicating_dikes; time_to_demand)
building_dikes	DELAY3(starting_dike_construction; time_to_build_dikes)
coastal_land_abandonment	fraction_land_at_risk*Agricultural_coastal_land
construction_effect_on_dikes_available	GRAPH(dikes_under_construction/Dikes) Points: (0,0611621, 0,995614), (2,50765, 0,872807), (4,98471, 0,644737), (7,52294, 0,390351), (9,90826, 0,00877196)
dike_gap	MAX(planned_dike-(dikes_under_construction+Dikes); 0)
Dikes_available	construction_effect_on_dikes_available*Dikes
effect_of_risk_of_floodings_on_coastal_farmland_abandonment	GRAPH(perceived_risk/acceptable_risk) Points: (0,0183486, 1,500), (0,293578, 1,44737), (0,48318, 1,40351), (0,752294, 1,32456), (0,978593, 1,12281), (1,1682, 0,684211), (1,34557, 0,473684), (1,66361, 0,149123), (1,97554, 0,0350877)
forecast_of_dikes_construction	DELAY(time_to_demand; time_to_build_dikes; indicating_dikes)
fraction_land_at_risk	normal_land_fraction_at_risk*effect_of_risk_of_floodings_on_coastal_farmland_abandonment
indicating_dikes	pressure_to_expand_dikes*normal_land_fraction_at_risk*Agricultural_coastal_land/acceptable_risk
normal_land_fraction_at_risk	0,4
perceived_risk	SMTH1(risk_of_floodings; time_to_perceive_risk; acceptable_risk)
planned_dike	(1-weight_on_forecast)*average_dike_demand+weight_on_forecast*forecast_of_dikes_construction
pressure_to_expand_dikes	GRAPH(risk_of_floodings/acceptable_risk) Points: (0,00611621, 0,0087719), (0,35474, 0,0701754), (0,501529, 0,192982), (0,752294, 0,438596), (0,899083, 0,649123), (0,996942, 1,00877), (1,10092, 1,2807), (1,23547, 1,50877), (1,5107, 1,7807), (1,73089, 1,86842), (1,98777, 2,00877)
risk_of_floodings	Agricultural_coastal_land*fraction_land_at_risk/Dikes_available
time_to_build_dikes	2
time_to_demand	2
time_to_perceive_risk	1
time_to_plan_dikes	3
weight_on_forecast	0.5

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5.4.3 Synthetic reflection on the quantification process for the different SD sub-models

The major sources of quantitative information come from reports, studies and statistical reports (Agreste; SAGE; Mémento de la statistique agricole; Charente tourism; SAFER, Façade Sud-Atlantique; Flash Info Maline). These sources where used first to have rough values of variables for developing models. The advantage of using these rough values comes from their prompt availability. We plan to use statistical reports for calibration and some time series served as inputs for some variables. Relevant and validated data are stored in database for later use. The quantification process is still in progress and complete information will be included in the following relevant COASTAL Deliverables.

5.4.4 Plan for scenario analysis using the SD sub-models

The main challenges and common objectives of the MAL4 territories for a desirable future (2040-2050) were discussed with stakeholders during the workshops (Tiller et al., 2019b). There are identified as the restoring and preserving of natural environments and limiting impact of economic activities and population on the water resources, soils and biodiversity. Preservation and/or development of main economic activities in the area such as agriculture, shellfish farming, and tourism were also discussed. There is then a need to explore different scenarios on the way to reach these goals that are sometimes conflicting (Viaene et al., 2020).

By highlighting interdependencies between activities and possible synergies, by identifying the most relevant pathways and actions to reach this desirable future, SD models that we developed/are developing are intended to help analyze the potential consequences of actions and find pathways to sustainability.

For MAL4, the key problems that address the SD models are the evolution of agriculture, the increase in coastal population, the maintenance or development of sustainable shellfish farming systems.

For the agriculture issue, we intend to assess (i) the evolution of agriculture and the consequences of agriculture development on land and water availability, and on infrastructure development; (ii) the development of organic farming with opportunities for new crops requiring less water and new short supply chains and its impact on ports development; and (iii) the development of water storage reservoirs and its impact on the water resource and crops diversification.

For the issue of increasing population (residential and tourism), we intend to assess (i) the consequences of increasing population on the quality of surface and coastal waters and dependent ecosystems with impact on shellfish farming. Some of the potential scenarios and their relation to the key policy frameworks are presented in Table 31.

Table 31. Types of scenarios that may be testable/tested through the SD modelling in MAL4 and their relations to topics/scenarios in the listed overarching frameworks (European Green Deal topics, Figure 9; SDGs: UN Sustainable Development Goals in Agenda 2030, Figure 10; SSPs: Shared Socioeconomic Pathways, Figure 11; Topics in applicable MSP: Marine Spatial Plan).

Types of scenarios for SD modelling	Indicate if the scenarios can be related to any of the overarching frameworks and briefly to which framework topic(s)/scenario(s)			
	Topic in EU Green Deal	SDGs	SSP scenarios	Topic in MSP
Development of organic farming (up to 30%) within the hinterland and its impact	Yes Form farm to fork (Protect the environment and preserve biodiversity; Increase organic farming; Ensure a fair economic return in the supply chain)	Yes SDG 12	Yes SSP1	Coexistence of uses; Land-sea interactions

Decrease of intensive irrigated farming and increase in environmental friendly practices and their impact	Yes Form farm to fork (Protect the environment and preserve biodiversity; Increase organic farming; Ensure a fair economic return in the supply chain)	Yes SDG 12	Yes SSP1	Coexistence of uses; Land-sea interactions
Maintenance of extensive livestock breeding and associated grasslands on the coastal zone	Yes Form farm to fork (Protect the environment and preserve biodiversity)	No	Yes SSP1	Coexistence of uses; Land-sea interactions
Development of sustainable coastal and rural tourism by limiting concentration of infrastructure and people	Yes Marine Strategy Framework Directive; MSP	Yes SDG 12	Yes SSP1	Protect marine environment and preserve marine biodiversity; Coastal tourism
Collective improved water management in the hinterland and impacts on shellfish farming, on drinking water supply and water treatment plants	Yes Form farm to fork (Protect the environment and preserve biodiversity)	Yes SDGs 6, 14	Yes SSP1	Protect marine environment and preserve marine biodiversity; Aquaculture
Development of agricultural supply chains for export and impact on ports infrastructure	Yes CAP; Integrated maritime policy	Yes SDG 9	Yes SSP1	Land-sea interactions

5.4.5 Data/Model sources and general references

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5.5 Multi-Actor Lab 5. Danube Mouth (Black Sea) - Romania

5.5.1 Introduction and problem scope for land-sea SD modelling

The Danube River Basin is Europe's second largest river basin, and 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[19]. As both the largest remaining natural wetland and second largest river delta in Europe, the Danube Delta is one of the 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. However, local contribution has a major role as well. 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, its branches, and several canals are the major sources of water for industrial, agricultural (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 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 Danube Delta Biosphere Reserve (DDBR)[20] 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 neighboring 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 37).

[19] https://www.icpdr.org/main/danube-basin
[20] http://www.ddbra.ro/en/danube-delta-biosphere-reserve/danube-delta

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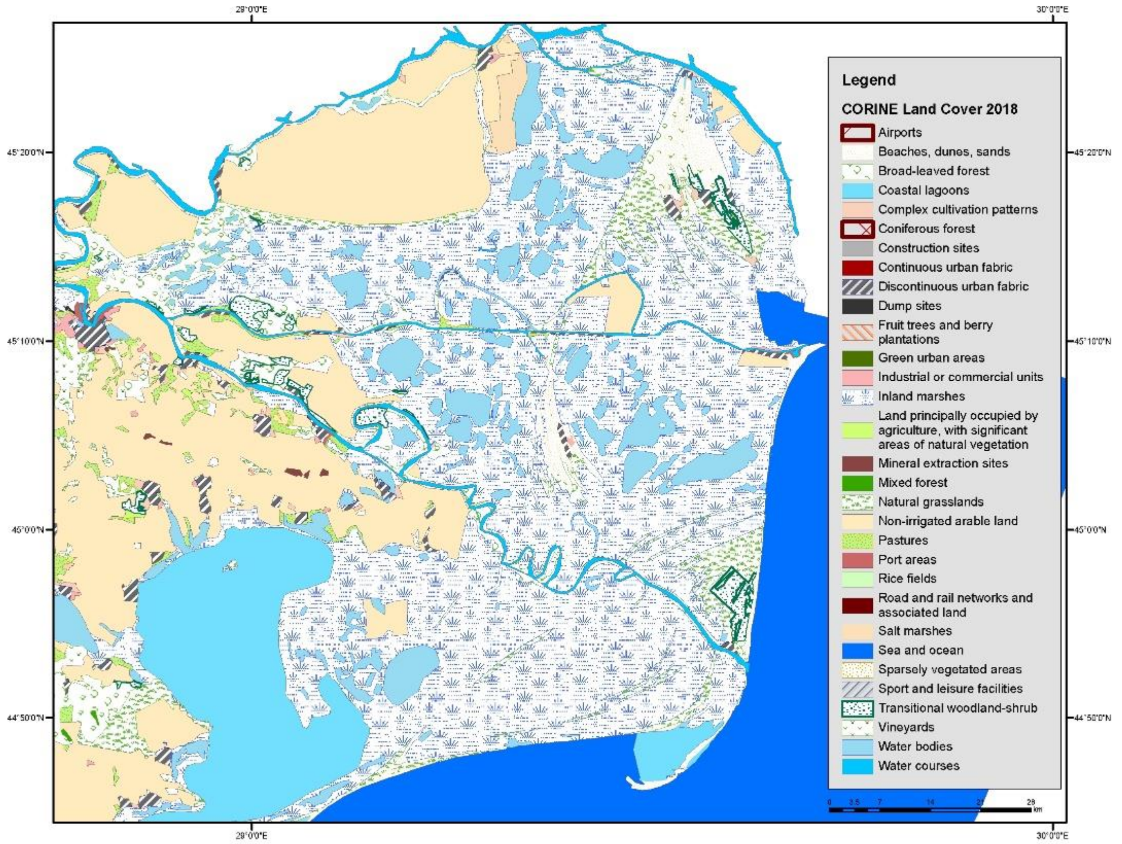

Figure 37. Map of the geographic area - Danube's Mouths – Black Sea case (MAL5).

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 (Tiller et al., 2019a and 2019b). 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 DDBR Authority. 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). Management of the Danube Delta should take into consideration several needs for the short and medium terms. For example, in the short term, 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. Environmental issues are mainly associated with the lack of environmental awareness as 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 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, or 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. In the Danube Delta, due to its high biodiversity and uniqueness of landscapes, the delta attracts about 150,000 tourists every year, which is ten times the number of inhabitants[21].

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). 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. 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, or small-scale businesses based on traditional activities (Sbarcea et al., 2019).

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.

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

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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 conclusions of all COASTAL meetings (with stakeholders, mental mapping seminar and multi-actor lab) (Tiller et al., 2019a and 2019b) 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"[22]. 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).

5.5.2 Quantified SD sub-models

To analyse the stakeholders meeting outputs (Tiller et al., 2019a and 2019b) in System Dynamics (SD) model we classified land-sea interaction "layers" as shown in Figure 38 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. The goal of the model is to explore alternative scenarios to improve the quality of life and sustainability within DDBR and its marine waters (Black Sea) as one of the most impacted area along the Romanian littoral.

[22] https://www.mlpda.ro/userfiles/delta_dunarii/rezultate_proiecte/2_Raport_Viziune_en.pdf

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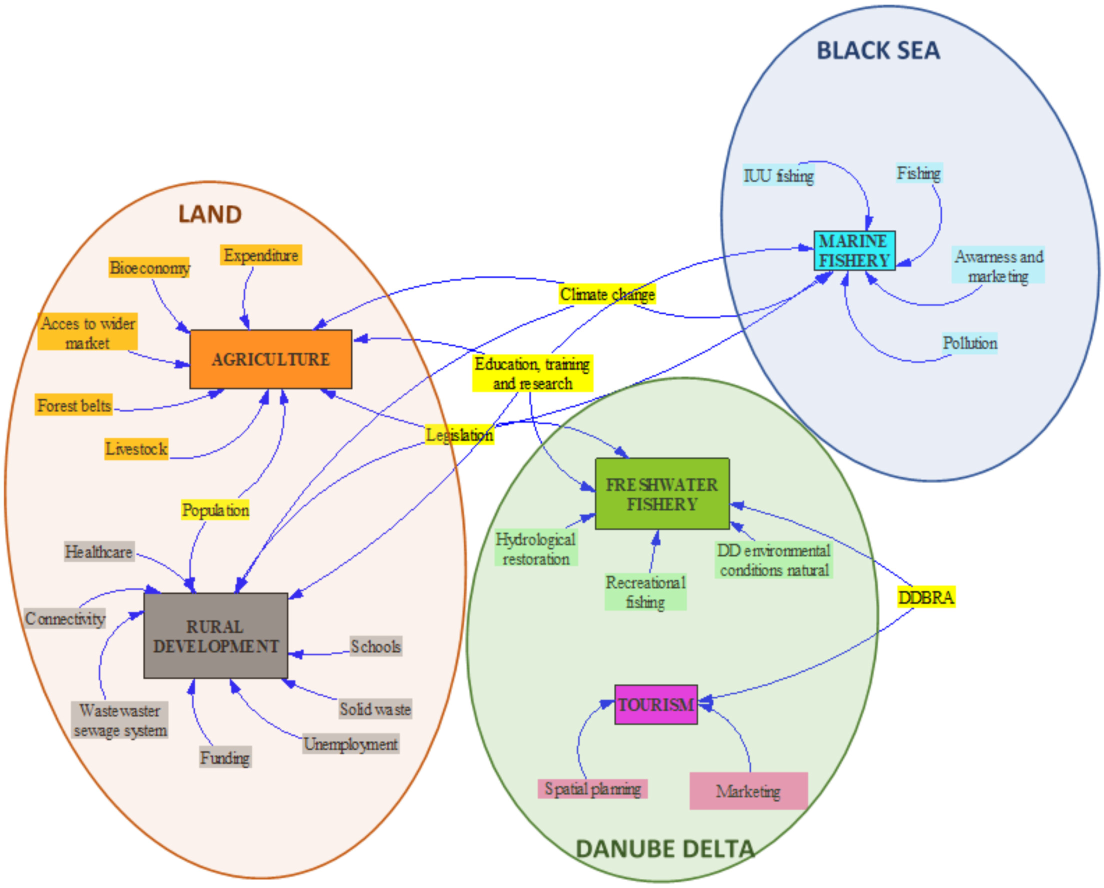

Figure 38. Land-sea interactions in MAL5 (DDBRA: Danube Delta Biosphere Reserve Authority; DD: Danube Delta; IUU: illegal fishing) (Viaene et al., 2020).

SD modelling in MAL5 is focused on land-sea interactions through the pollution sourcing in different sectors (agriculture, tourism, rural development) and possible solution pathways that may be driven by different actions. As the overall causal loop diagram (CLD) produced during work package (WP) 1 was considered unclear (Tiller et al., 2019b), it was decided to start from the sectoral CLD's (Tiller et al., 2019a) when producing SD sub-models. Based on the CLDs derived during the sectoral workshops and layers presented above, we identified six SD sub-models from the overall CLD to be designed and developed in COASTAL, as listed in Table 32. Various problem aspects that can be investigated in each sub-model are also outlined in this table. Considering data and model (results) availability in MAL5, two SD sub-models of Agriculture and Marine Fishery have been partially developed and quantified at this stage, and will be further explained in the following sections.

Table 32. List of developed SD sub-models, their associated problems and their quantification status (fully/partially/not yet quantified) in MAL5.

No.	Title of SD sub-model	Addressed problems	Status of quantification
1	Agriculture	Strengthening farmer's position in the value chain while protecting and maintaining a healthy environment	Partially quantified
2	Marine fishery	Marine fishermen welfare progress in opposition with fish stock reduction due to pollution from land-based sources, illegal fishing and lack of organize fish market.	Partially quantified
3	Freshwater fishery	Freshwater fishermen welfare progress in opposition with fish stock affected by clogged canals, illegal fishing, and lack of organized fish market.	Not yet quantified

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4	Tourism	Tourism is a significant sector for economic growth, but at the same time it affects the preservation of cultural heritage, the environment, infrastructure.	Not yet quantified
5	Rural development	Increasing the well-being of the population and encouraging the diversification of economic activities in rural coastal areas while decreasing the level of generated waste.	Not yet quantified
6	Ecosystem management	Biodiversity dynamics in conflict with rural and business development and lack of management for solid waste or pollution form other sectors.	Not yet quantified

5.5.2.1 Sub-model 1. Agriculture

5.5.2.1.1 Quantified key land-sea interactions and feedback structures in sub-model 1

According to the stock-flow (SF) structure of sub-model 1 shown in Figure 39, 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[23]. 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[24]. Although not specifically mentioned by the stakeholders, the variables Expenditure and Forest belts were added to the model.

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 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. Moreover, planting trees is part of the European Green Deal Biodiversity strategy. The forest belts offer multiple beneficial effects including biodiversity increase, reducing soil erosion, mitigating of flood risks, trapping snow, and increasing crop yields.

[23] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/bioeconomy
[24] https://www.oecd-ilibrary.org/docserver/9789264024786-en.pdf?expires=1595506959&id=id&accname=guest&checksum=1181168B0D5F1115C4F91D0AB20CE3F9

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Variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.5.5 (Viaene et al., 2020) and are also presented here in Table 33 with possibly some updates based on the sub-model progress in MAL5.

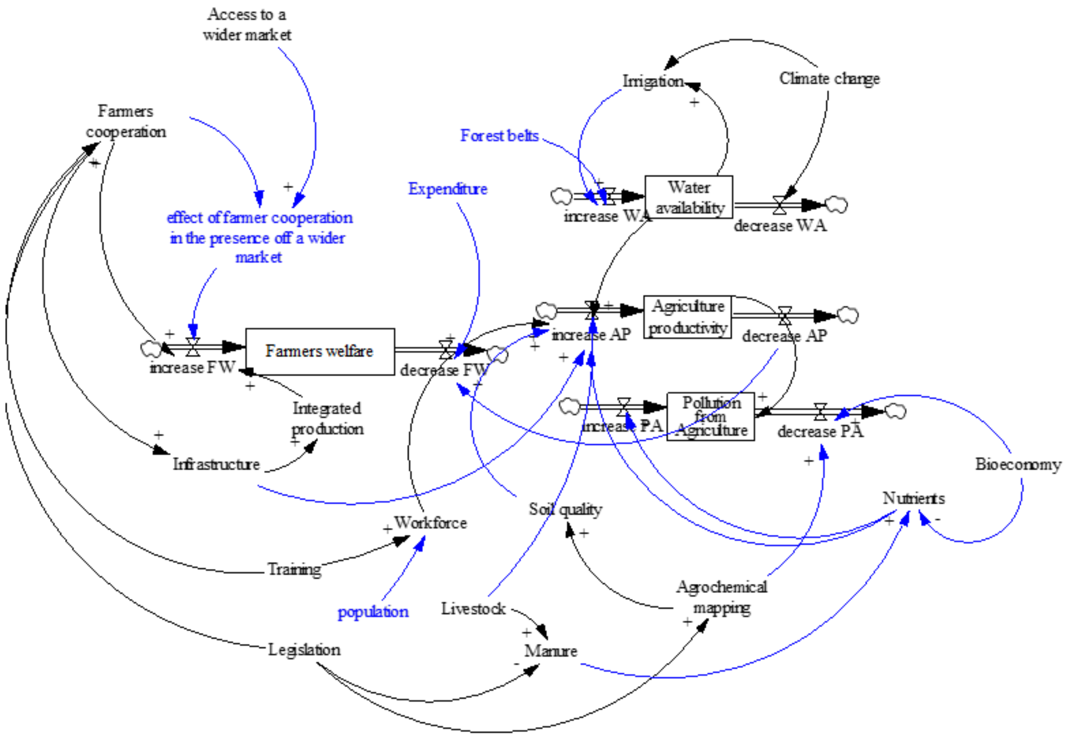

Figure 39. SF structure of SD sub-model 1 in MAL5 developed in Vensim software (Viaene et al., 2020).

Table 33. Main variables in SD sub-model 1 for MAL5 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Access to a wider market	dmnl	D	C	expanded access to markets - the core of a more robust agricultural economy
Agriculture productivity (AP)	dmnl	O	S	Index representing the efficiency of agricultural land, labour, capital, and materials (agricultural inputs)
Agrochemical mapping	dmnl	I	C	soil quality characterization as one of preconditions for good agronomic decision making
Bioeconomy	dmnl	D	C	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	I	Lu	Floods and Droughts
Climate change related to temperature	°C	I	Lu	Index of actual temperature vs average temperature of previous years
increase/decrease AP	t/y	I	F	rate of increasing/decreasing agriculture productivity

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increase/decrease FW	RON/y	I	F	rate of increasing/decreasing farmers welfare
increase/decrease PA	t/y	I	F	rate of increasing/decreasing pollution from agriculture
increase/decrease WA	t/y	I	F	rate of increasing/decreasing water availability
Production value	RON	I	Lu	Net income from the agricultural production
Expenditure	RON	I	Lu	costs of production borne by farmers consisting of variable input costs (fertilizers, pesticides, feed, etc.), depreciation, and taxes
Farmers cooperation	dmnl	I	C	an association where farmers pool their resources in certain areas of activity
Farmers welfare (FW)	RON	O	S	net income of farmers
Forest belts	m^2	I	C, A	Area covered with Forest belts within the case study region
Infrastructure	dmnl	I	C	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	I	C	Integration is a competitive strategy by which a farmer takes control over one or more stages in the production or distribution of an agro-food product.
Irrigation	ha	I	Lu	agricultural area irrigated (the area on which irrigations were carried out at least once in an agricultural year)
Legislation	dmnl	D	C	law and rules applicable for agriculture practices to protect the environment and for farmers association
Livestock	Number of LU	I	Lu	The total number of livestock units (LU) of the holdings with livestock.
Manure	Tonnes active substance	I	Lu	Quantity of natural fertilisers applied in agriculture, the natural fertilizers - manure from all species of domestic animals and poultry (fresh or sour), also the compost in liquid form, measured in brutto weight.
Nutrients	Tonnes active substance	I	Lu	Quantity of chemical fertilisers applied in agriculture. The chemical fertilizers are industrial products which can be separately nitrogenous, phosphatic and potassic fertilisers or combinated as complex fertilisers (active substance).
Pollution from Agriculture (PA)	dmnl	O	S	Index of agriculture effect on environment
Population	individuals	I	Lu	all persons who have their usual residence in the studied area
Precipitation	mm	I	Lu	Quantity of precipitations within the case study area
Soil quality	dmnl	I	C	capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity
Education	individuals	I	Lu	number of -schools' graduates

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Water availability	dmnl	O	S	water quantity available for irrigation and livestock production
Workforce	individuals	I	Lu	number of employees in agriculture

5.5.2.1.2 Outline of quantitative information to support sub-model 1

We started step by step the quantification with the agricultural production and farmers' welfare (FW). Several variables were added or renamed (Figure 40). Because (AP, t/ha) is the main rationale for this activity, this stock returns the integral of growth AP (t/ha/y) (Equation (55)) with an initial value:

$$Growth\ AP = AP \times Expected\ growth\ AP \times \left(1 - \frac{AP}{AP_{max}}\right) \qquad (55)$$

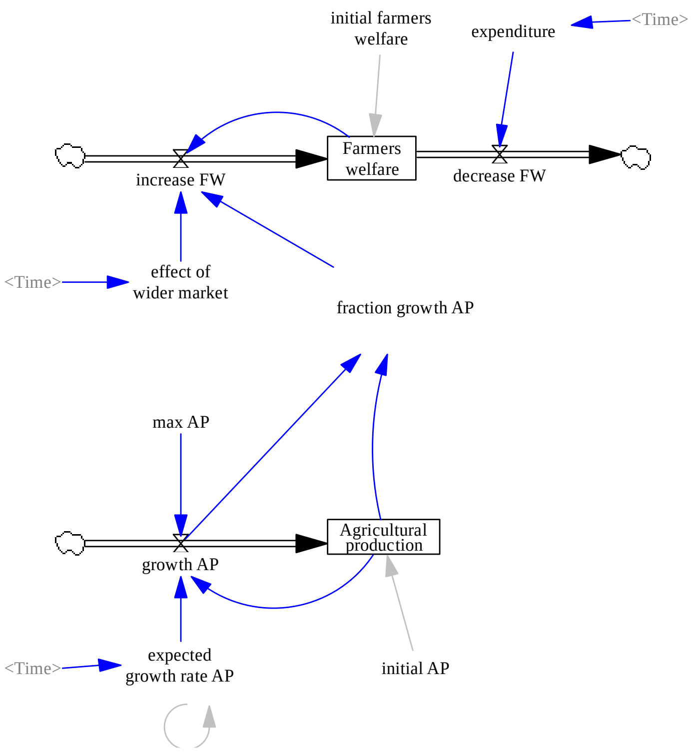

Figure 40. Agricultural production and farmers' welfare in SF structure of SD sub-model 1 in MAL5.

The expected growth rate in agricultural production is considered due to better management of livestock, soil quality, nutrients, water availability and human capital. AP is defined as the ratio of farm outputs to farm inputs. The outputs taken into consideration are crops and livestock. When possible, other outputs may be added, such as dairy products, meat products, wool, etc. The inputs are sum of labour, capital, land, materials and services used in the agricultural production. AP will give an insight on the output produced with available inputs. AP is influenced by internal factors (farm size, the farmer's managerial ability, qualified workforce and investments) and external factors (legislation, access to infrastructure, climate change- draughts or rainy seasons).

The other stock, farmers' welfare (FW, RON), is describing the evolution of agricultural income and is calculated according to Equation (56):

$$Stock_t = Stock_{t-1} + dt \cdot increase\ FW_t - dt \cdot decrease\ FW_t \qquad t = 2, 3, 4, \ldots, 100 \qquad (56)$$

$$Stock_1 = Stock_{initial} = FW_t \; at \; intial \; time \tag{57}$$

where, $Stock_t$ and $Stock_{t-1}$ are values of FW at time t and t-1, respectively, and $increase\, FW_t$ and $decrease\, FW_t$ are increasing and decreasing rates of FW at time t (RON/y), respectively. The main factors influencing the increasing of FW are the effect of wider market (look-up) and a fraction of growth AP (calculated as growth AP/AP). In our sub-model, expenditures (look-up) are the major decreasing causes for FW, and imply the costs of production borne by farmers consisting of variable input costs (seeds, fertilizers, pesticides, feed), depreciation, and taxes.

The water availability for agricultural sector is a problem to be tackled by the sub-model 1, due to adverse effects of climate change that bring about draught seasons during last years (Figure 41). The increase of water reserve is a function of precipitation (look-up function), beneficial effects of forest belts and cover crops (auxiliary variables).

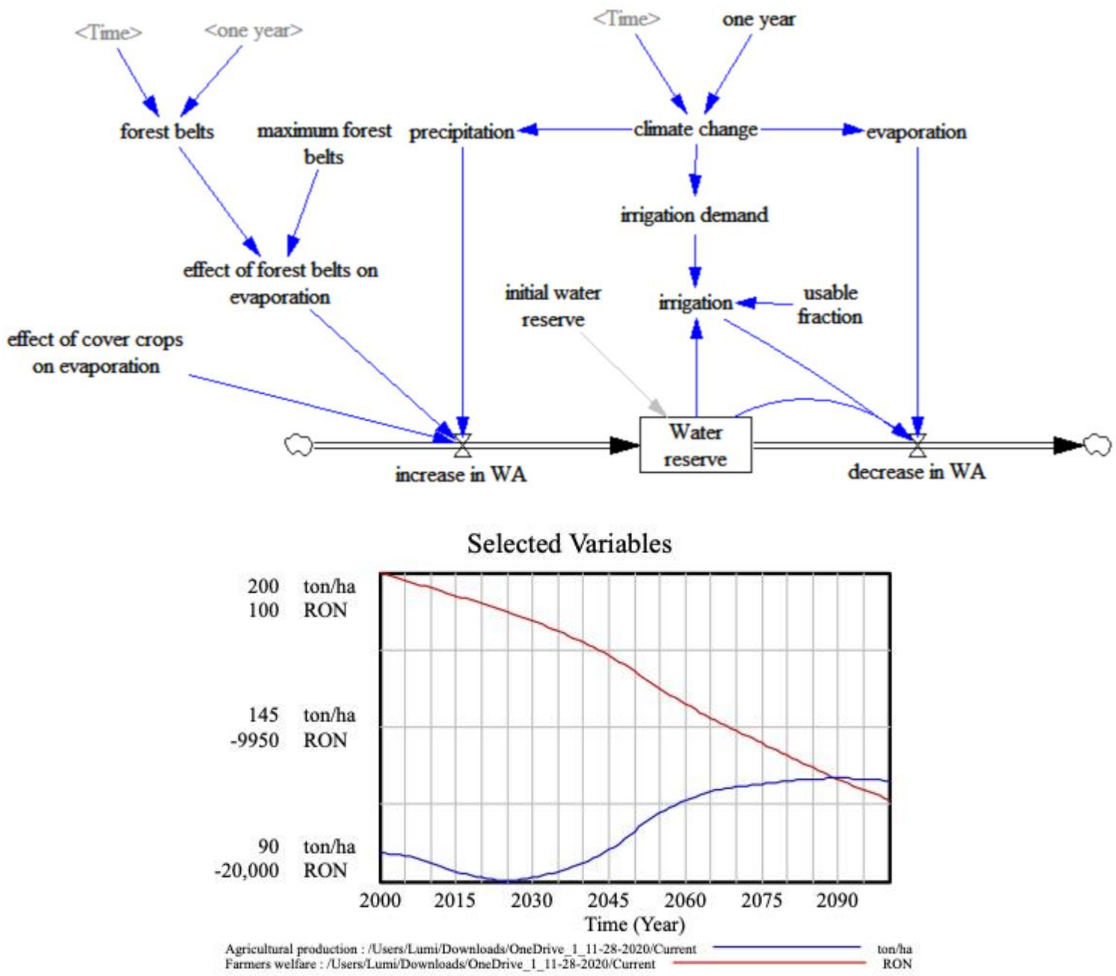

Figure 41. Water availability in SF structure of SD sub-model 1 in MAL5.

Finally, the effects of agriculture on environment will be calculated, taking into consideration the inflow to accumulation of pollutants and the degeneration rate (Figure 42). Inflow is sum of agrochemicals use and nutrients. The agrochemicals use is calculated by Equation (58):

AU = effect of mapping on agrichemicals use * effect of bioeconomy on agrochemical use * current AU (58)

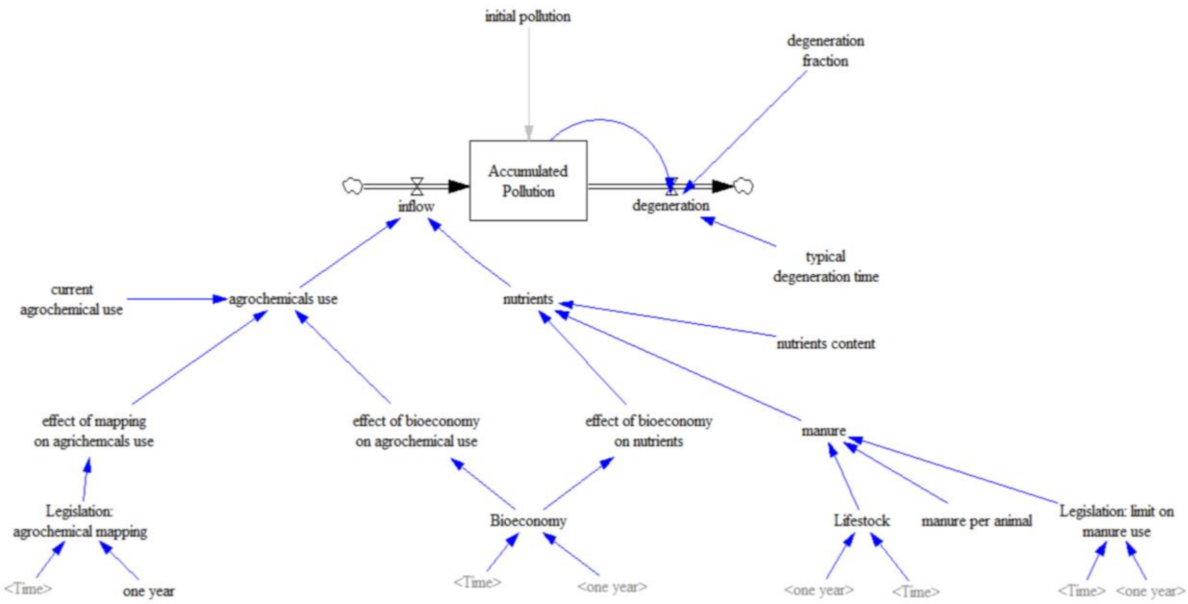

Figure 42. Accumulated pollution in SF structure of SD sub-model 1 in MAL5.

Sub model 1 is partially quantified. Data collection and decision rules assessment are under progress. However, several additions will be operated, such as introducing organic agriculture as factor for decreasing the accumulated pollution.

5.5.2.2 Sub-model 2. Marine fishery

5.5.2.2.1 Quantified key land-sea interactions and feedback structures in sub-model 2

This sub-model has three stocks – marine fish stock (MFS), marine aquaculture (MA) which increases with inflows and outflows (increase/decrease MFS, increase/decrease MA as blue growth element), and marine fishermen welfare, added to quantify net income. Awareness and marketing are one of the important drivers for an increase in the consumption of aquaculture products. Thus, in our model dynamics in MFS depends on education, training and research as scientific support for policies and decision makers (Legislation) regarding fishing restrictions. Another important aspect is represented by illegal fishing (IUU) and pollution which are reinforcing MFS to decrease. Marine aquaculture production and MFS are increased by education, training and research and the fish market as one of the main components of the growing fishermen's welfare. All are influenced by pollution from land as one of the main land-sea interactions (Figure 43). Key variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.5.5 (Viaene et al., 2020) and are also presented here in Table 34 with possibly some updates based on the sub-model progress in MAL5.

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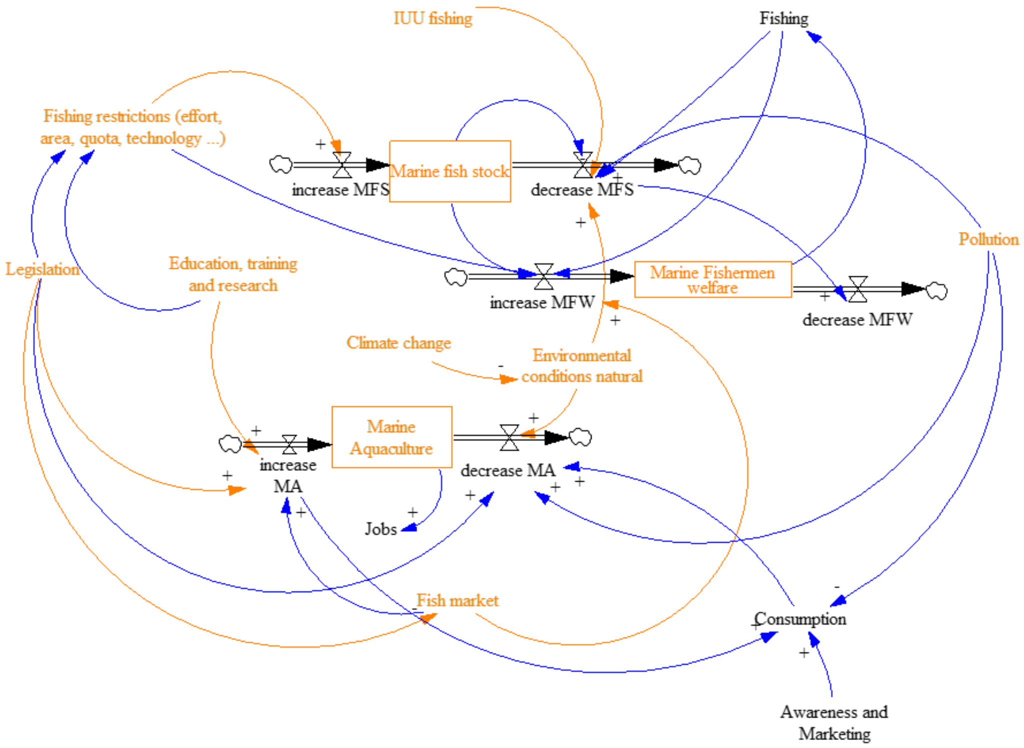

Figure 43. SF structure of SD sub-model 2 in MAL5 developed in Vensim software (Viaene et al., 2020).

Table 34. Main variables in SD sub-model 2 for MAL5 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Awareness and Marketing	dmnl	D	A	awareness and marketing channels and campaigns for aquaculture product consumption acceptance
Climate change related to seawater	ºC	D	Lu	Seawater temperature
Consumption seafood	t	I	A	aquaculture products consumption
Increase/decrease MA	t/y	I	F	rate of production/harvesting of marine aquaculture stock
Increase/decrease MFW	RON/y	I	F	rate of increasing/decreasing of marine aquaculture biomass
Increase/decrease MFS	t/y	I	F	rate of increasing/decreasing of marine aquaculture biomass
Education, training and research	RON	D	A	funds for knowledge based on scientific support for marine fishery activities
Environmental conditions natural	dmnl	I	Lu	background (natural variability) Black Sea water quality
Fish market	t	I	C	wholesale fish market facility
Fishing	t	D	Lu	annually total fish capture (Black Sea) from the studied area
Fishing restrictions	dmnl	I	C	Regulation limiting unwanted catches, juvenile fish or endangered species
IUU fishing	t	D	Lu	Illegal, unreported and unregulated (IUU) fishing is a broad term that captures a wide variety of fishing activities. IUU fishing is found in all types and dimensions of

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				fisheries; it occurs both on the high seas and in areas within national jurisdiction.
Jobs	employees	I	Lu	number of employees from the marine fishery sectors
Legislation	dmnl	D	C	law and rules applicable for fishery development and environmental (fish) protection
Marine Aquaculture (MA)	t	O	S	annually (Black Sea) production from fish and shellfish farming
Marine fish stock (MFS)	t	O	S	fish biomass available for fishing in the studied area
Marine Fishermen welfare (MFW)	RON	O	S	net income of marine fishermen
Pollution	dmnl	D	A	Index of seawater pollution

5.5.2.2.2 Outline of quantitative information to support sub-model 2

We started step by step the quantification with Marine Aquaculture Stock (MAS). Several variables were added or renamed (Figure 44). Thus, the increase/decrease of MAS (t) are named production and harvest and the stock is described by the equation *production-harvest*.

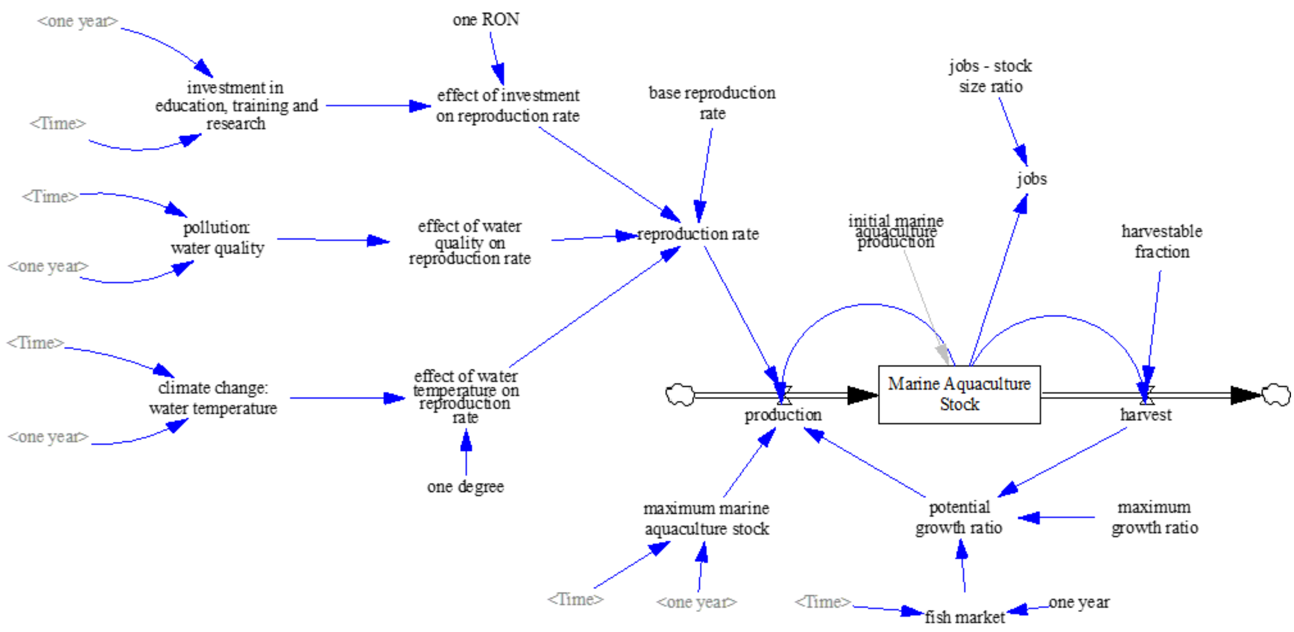

Figure 44. Marine Aquaculture Stock in SF structure of SD sub-model 2 in MAL5.

Consequently, value of MAS is quantified based on its connected inflow (production) and outflow (harvest) rate variables as Equation (59):

$$Stock_t = Stock_{t-1} + dt \cdot Production_t - dt \cdot Harvest_t \qquad t = 2, 3, 4, \dots, 100 \qquad (59)$$

$$Stock_1 = Stock_{initial} = MS_t \ at \ intial \ time \qquad (60)$$

where, $Stock_t$ and $Stock_{t-1}$ are values of MAS at time t and t-1, respectively, and $Production_t$ and $Harvest_t$ are production and harvest of MAS at time t (t/y), respectively. As a decision rule, MAS production (t/y) is a function of reproduction rate and potential growth ratio, both as new variables, as Equation (61):

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$$Production = (1 - \left(\frac{MAS}{MAS_{max}}\right)) \times MAS \times (Reproduction\ rate \times Potential\ growth\ ratio) \quad (61)$$

The rate of reproduction for the cultured species, calculated based on Equation (62), has included apart from their natural features (base reproduction rate) the effects of climate change seawater temperature – look-up table, water quality – which is an index considering all the pollution from land-based activities and investment in education, training and research.

$$Reproduction\ rate = base\ reproduction\ rate \times effect\ of\ investment \times effect\ of\ water\ quality \times effect\ of\ water\ temperature \quad (62)$$

The latter was invoked by the stakeholders and it is considered to create a scenario. However, this funding source is usually subject to strict legal rules as well as to economy scarcity constraints. These restrictions, which represent a saturation level, along with an exponential rush in an economic competition for money, create an aggregate national response as a sigmoid curve[25,26]. Therefore, it was considered as sigmoid increase through fixing point with minimum investment=0, maximum investment=100, minimum effect=1, maximum effect=2 (Figure 45). Using this function might require the normalization of look-ups (allocated funds for knowledge based on scientific support for marine fishery regulation and activities).

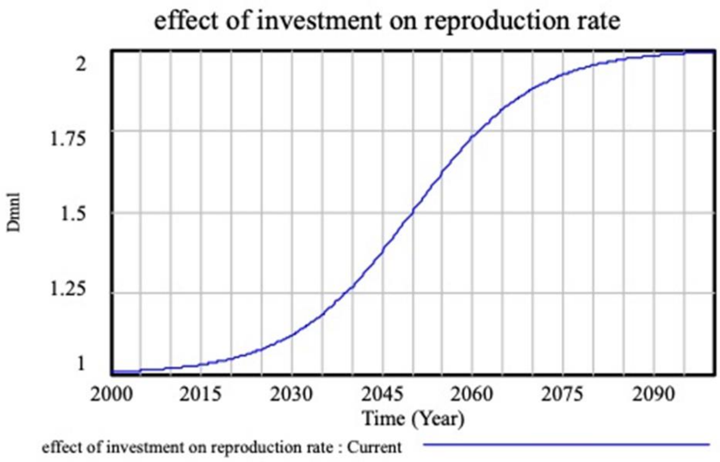

Figure 45. Sigmoid function of effect of investment on reproduction rate, used in SD sub-model 2 in MAL5.

The effect of water quality is a power function which increase slowing down to saturation level (fmax) (minimum water quality=0; maximum water quality=100; minimum effect=0 (no reproduction); maximum effect=1). The effect of temperature is also described by a power function which decrease accelerating to minimum level (fmin) as shown in Figure 46 (minimum water temperature =14; maximum water temperature=16, minimum effect=0; maximum effect=1).

[25] https://metasd.com/2020/02/s-shaped-functions/
[26] https://metasd.com/model-library/

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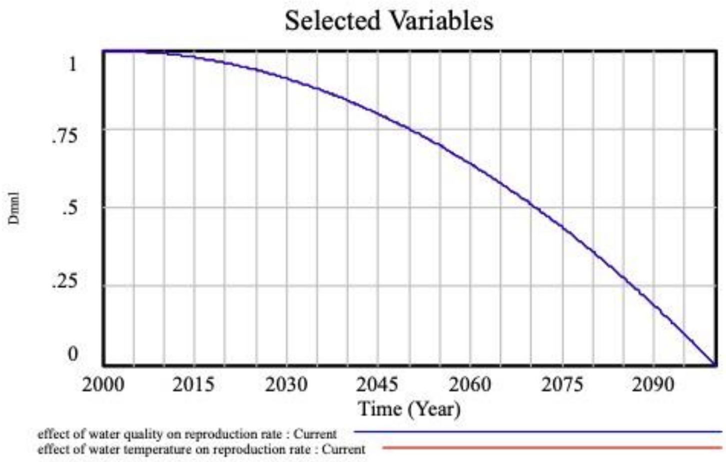

Figure 46. Power function of effect of water temperature as a climate component and water quality on reproduction rate, used in SD sub-model 2 in MAL5. The two curves are overlapping.

On the other hand, the potential growth ratio is defined by MIN (maximum growth ratio, fish market/harvest). The variable (auxiliary) *Maximum Marine Aquaculture Stock* (t) was included because in the sub-model 2 structure marine aquaculture production is limited by legislation mainly as the area under concession.

The main drivers in sub-model 2 are investment in education, training and research, water pollution, climate change (seawater temperature), species natural features (base reproduction rate), legislation (maximum marine aquaculture stock), and fish market. Preliminary results of the scenario of reducing pollution from land-based sources - water quality is improving from bad to high - and progressively increasing of sea surface water temperature by 2 °C displayed a sharped increase of MAS followed by a stabilized high production and a sharp decrease in the end of interval, as shown in Figure 47.

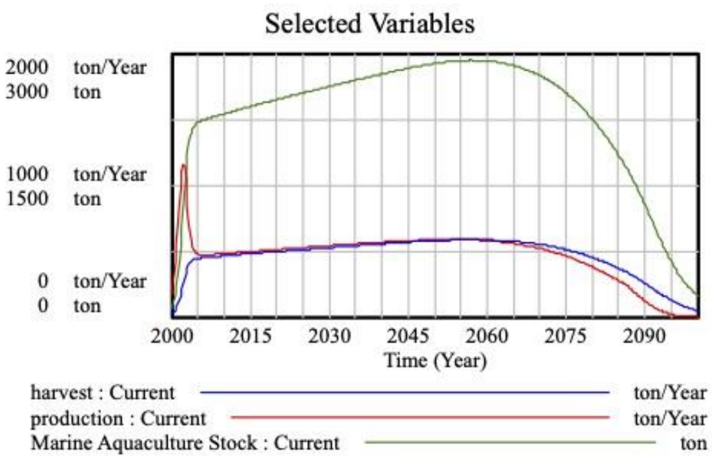

Figure 47. Preliminary results of change in MAS as part of SD sub-model 2 in MAL5.

5.5.2.3 Sub-model 3. Freshwater fishery

5.5.2.3.1 Quantified key land-sea interactions and feedback structures in sub-model 3

Pollution is including in this sub-model the upstream of the Danube's waters quality and eutrophication and the environmental conditions are in the context restricted to the 'freshwater environmental condition' of the Danube Delta natural characteristics (including the background from the upstream). In this regard, our research 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 (MDRAP, 2016). 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 (Tiller et al., 2019b). The model structure has three stocks as Freshwater fishermen welfare, Freshwater fish, and Freshwater aquaculture as shown in Figure 48. All variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.5.5 (Viaene et al., 2020) and are also presented here in Table 35 with possibly some updates based on the sub-model progress in MAL5.

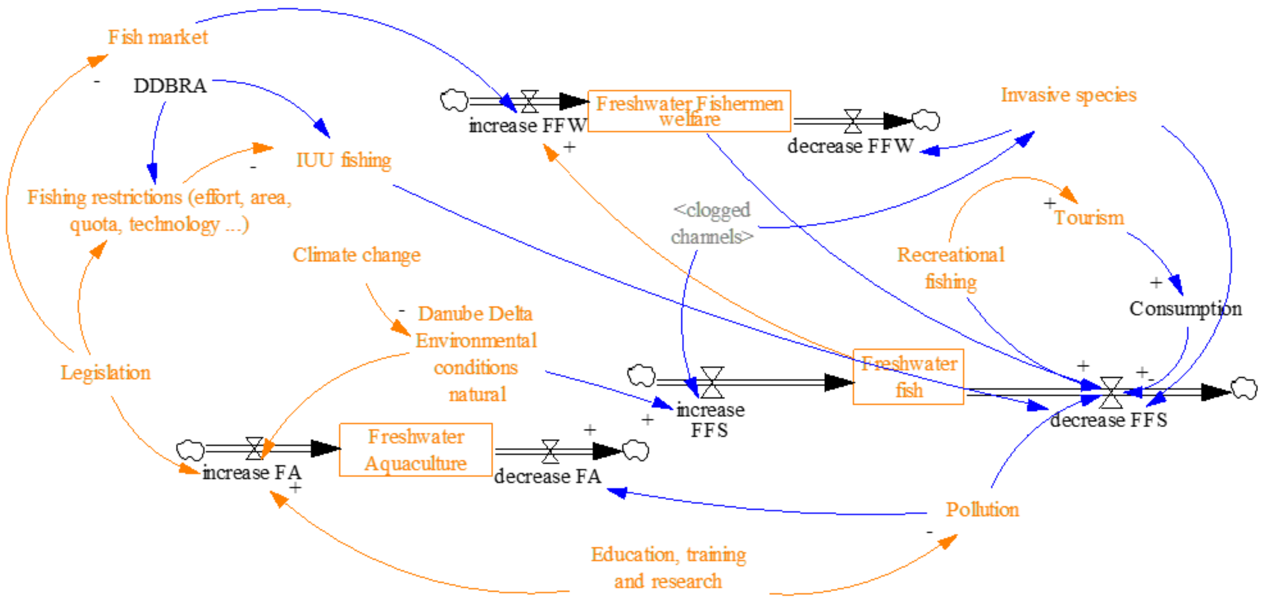

Figure 48. SF structure of SD sub-model 3 in MAL5 developed in Vensim software (Viaene et al., 2020).

Table 35. Main variables in SD sub-model 3 for MAL5 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Climate change related to River flow	dmnl	D	Lu	Floods and Droughts events
Consumption	t	I	Lu	Quantity of fish consummated by one person (annually average)
DDBRA	dmnl	I	C	Danube Delta Biosphere Reserve Administration
Upstream Danube water quality	dmnl	I	Lu	Index of Danube's water quality (the upstream waters entering Danube Delta)
Increase/decrease FA	t/y	I	F	rate of increase/decrease of freshwater aquaculture
Increase/decrease FFS	t/y	I	F	rate of increase/decrease of freshwater fish stock
Increase/decrease FFW	RON/y	I	F	rate of increase/decrease of freshwater fishermen welfare
Freshwater Aquaculture (FA)	t	O	S	Production of freshwater aquaculture

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Freshwater fish (FFS)	t	O	S	Freshwater fish stock
Freshwater Fishermen welfare (FFW)	RON	O	S	Income of freshwater fishermen
IUU fishing	t			Same as in marine fishery
Legislation	dmnl	D	C	law and rules applicable for agriculture practices to protect the environment and for fishermen
Recreational fishing	t	I	Lu	annual fish capture in a recreational scope
Research	RON	I	Lu	funds for knowledge based on scientific support for freshwater fishery activities

5.5.2.3.2 Outline of quantitative information to support sub-model 3

This sub-model is not quantified yet. Data inventory, collection and model implementation are still in progress.

5.5.2.4 Sub-model 4. Tourism

5.5.2.4.1 Quantified key land-sea interactions and feedback structures in sub-model 4

The sub-model structure has a main balancing loop as Tourism – Pollution – Biodiversity – Tourism. Thus, this sub-model considers that the increase of tourism causes as main consequence an increase in pollution which leads to biodiversity loss. Once the biodiversity has degraded, the area is no more a touristic attraction. Pollution from tourism, Tourism business development, Biodiversity and Clogged channels are the stock variables in this sub model as shown in Figure 49. Main variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.5.5 (Viaene et al., 2020) and are also presented here in Table 36 with possibly some updates based on the sub-model progress in MAL5.

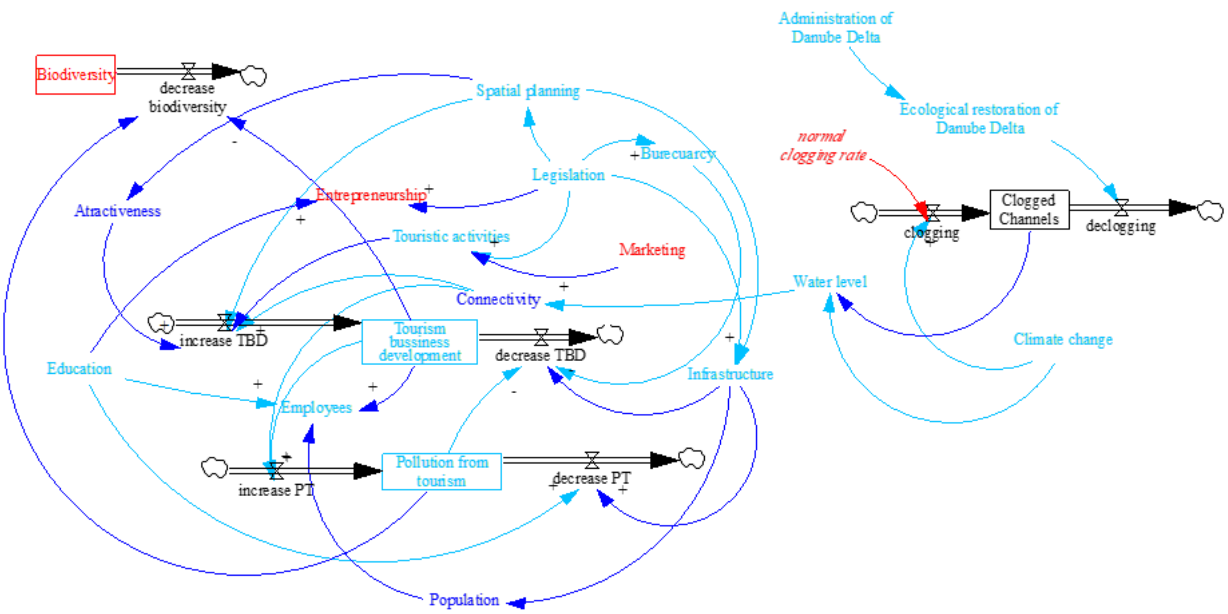

Figure 49. SF structure of SD sub-model 4 in MAL5 developed in Vensim software (Viaene et al., 2020).

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Table 36. Main variables in SD sub-model 4 for MAL5 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
DDBRA	dmnl	D	C	Danube Delta Biosphere Reserve Administration
Attractiveness	individuals	I	C	Returning tourists
decrease biodiversity	Species/y	I	F	Rate of decreasing number of species
Increase/decrease PT	t/y	I	F	Rate of increasing/decreasing of Pollution from Tourism
Increase/decrease TBD	RON/y	I	F	Rate of increasing/decreasing of Tourism Business
Employees	individuals	I	A	Number of employees in the tourism sector
Entrepreneurship	dmnl	I	C	Index of specific parameters for entrepreneurship (Number of accommodation units, Turnover, number of employees)
Legislation	dmnl	I	C	law and rules applicable for practices to protect the environment from tourism activities
Pollution from tourism	t	O	S	quantity of pollution generated by tourism

5.5.2.4.2 Outline of quantitative information to support sub-model 4

This sub-model is not quantified yet. Data inventory, collection and model implementation are still in progress.

5.5.2.5 Sub-model 5. Rural development

5.5.2.5.1 Quantified key land-sea interactions and feedback structures in sub-model 5

Rural business represents in this sub-model the non-agricultural business as part of rural economy (other than tourism) such as: circular economy business models, manufacture, etc. The stock variable lifestyle is used to describe how attractive living in the rural coastal area is (Figure 50). This is like measuring the quality of life. The quality of life is identified in terms of service provision, and it affects demography (population): if lifestyle is decreasing, people will want to leave the area and population will decrease. This stock will be quantified as the availability of healthcare, education, economic opportunities, environmental conditions, human pressure, and the overall accessibility of the areas.

Pollution from basic services is assessed in terms of the environmental quality of the area. The flow that increases this stock originates from infrastructure (domestic input - wastewater sewage systems, solid waste, water supply). Pollution decreases due to the legislation (i.e. recycling, recovery, etc.) and local development strategies and infrastructure’s components (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 rural areas being composed of the following components: water treatment stations, healthcare services, connectivity (transportation, ICT), schools.

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Variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.5.5 (Viaene et al., 2020) and are also presented here in Table 37 with possibly some updates based on the sub-model progress in MAL5.

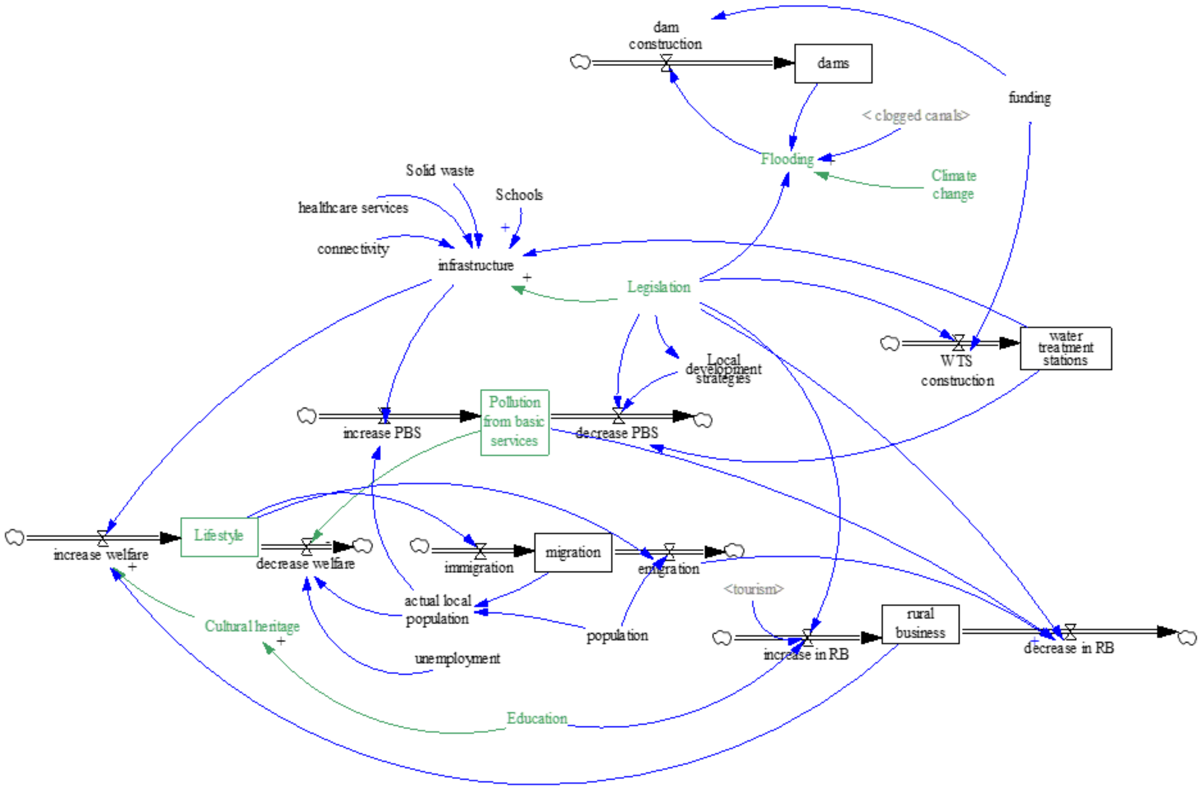

Figure 50. SF structure of SD sub-model 5 in MAL5 developed in Vensim software (Viaene et al., 2020).

Table 37. Main variables in SD sub-model 5 for MAL5 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Climate change related to river flow	dmnl	D	Lu	Floods and Droughts
Increase/decrease PBS	t/y	I/O	F	Rate of increasing/decreasing pollution from basic services
Increase/decrease welfare	RON/y	I/O	F	Rate of increasing/decreasing of population's welfare
Education	individuals	I	Lu	Number of people graduating from school forms
Legislation	dmnl	D	C	law and rules applicable for sustainable development
Migration	individuals	O	S	Net value calculated from immigration less emigration, by gender and age
Pollution from basic services (PBS)	t	O	S	quantity of pollutants (N, P, CBO5, solid waste) generated by the domestic population
Rural Business	dmnl	O	S	Index of income generated by rural business in the case study area
Schools	dmnl	I	Lu	Number of schools
Unemployment	individuals	I	Lu	Number of unemployed people

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5.5.2.5.2 Outline of quantitative information to support sub-model 5

This sub-model is not quantified yet. Data inventory, collection and model implementation are still in progress.

5.5.2.6 Sub-model 6. Ecosystem management

5.5.2.6.1 Quantified key land-sea interactions and feedback structures in sub-model 6

This sub-model highlights requirements for maintaining natural capital (water quality, biodiversity) as both a provider of economic input and output. 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).

This sub model is a connection within the different sub-models explained previously. The sub-model structure (Figure 51) contains all relevant stocks, flows and auxiliary variables related to environment. These are further supplemented with some new variables such as freshwater quality and Black Sea water quality, low economic fish species, birds. The Biodiversity stock was moved from sub-model 4 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 sub-model 3) and from marine fishery with Black Sea water quality (shadow variable defined in sub-model 2).

Variables in this sub-model were summarized in COASTAL Deliverable D13 – Section 3.5.5 (Viaene et al., 2020) and are also presented here in Table 38 with possibly some updates based on the sub-model progress in MAL5.

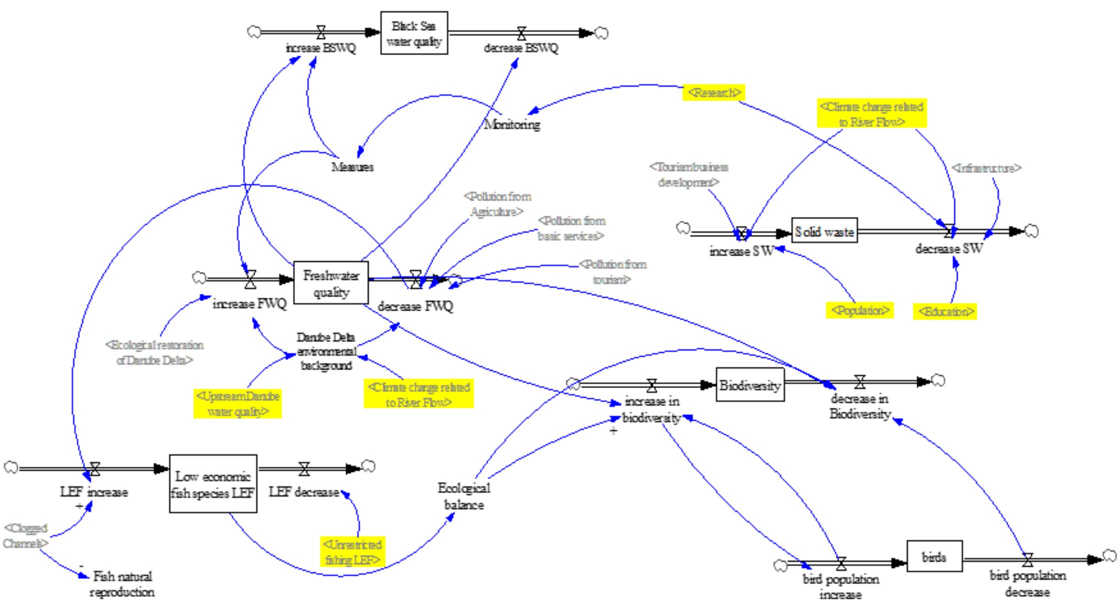

Figure 51. SF structure of SD sub-model 6 in MAL5 developed in Vensim software (Viaene et al., 2020).

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Table 38. Main variables in SD sub-model 6 for MAL5 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Black sea water quality	dmnl	O	S	Index of Black sea water quality
Biodiversity	dmnl	O	S	Total number of species in the area
Birds	dmnl	O	S	Total number of bird species in the area
Freshwater quality	dmnl	O	S	Index of freshwater quality
Low economic fish species	t	O	S	Species proliferated as invasive species or resilient to pollution
Solid waste	t	O	S	Solid waste generated by locals and tourists
Increase/decrease of biodiversity	dmnl	I	F	Rate of biodiversity increasing/decreasing
Increase/decrease of birds	dmnl	I	F	Rate of bird number increasing/decreasing
Increase/decrease of freshwater quality	dmnl	I	F	Rate of freshwater quality increasing/decreasing
Increase/decrease of low economic fish stock	t/y	I	F	Rate of low economic fish stock increasing/decreasing

5.5.2.6.2 Outline of quantitative information to support sub-model 6

This sub-model is not quantified yet. Data inventory, collection and model implementation are still in progress.

5.5.3 Synthetic reflection on the quantification process for the different SD sub-models

Our sub-models represent collections of associated elements established through consultation with stakeholders and sharing a common purpose, the sustainable development of the Danube Delta reserve and the Romanian Black Sea littoral. The general strategy for development of the partially quantified sub-models of 1 and 2 was to design and implement these sub-models step-by-step and integrate additional details only when needed and based on feedback of the actor partners involved in the model design. This is always a good strategy when developing SF models and was discussed and agreed on consultation with WP4 coordinator - VITO. The starting point with the two partially quantified sub-models was addressing agricultural production and marine aquaculture stock as important factors (but not only) for future planning of pollution management. Furthermore, these SF sub-models will use a spreadsheet including time series for look-up variables. We will follow the same strategy for further development of these sub-models and the other ones.

The two partially developed and quantified sub-models in MAL5 will be further quantified using established openly available data, model equations and results, and modeling approaches that are published in relevant official national assessment reports or peer-reviewed scientific publications. The two partially developed SD sub-models in MAL5 will support evaluation of system behavior in relation to the addressed pollution problems under possible local/regional development/change scenarios.

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5.5.4 Plan for scenario analysis using the SD sub-models

The partially quantified SD sub-models in MAL5 will be used to test various types of local/regional development/change scenarios, as listed in Table 39 and address the scenario implications for land-sea interactions and associated water quality (pollution from different activities) changes in the Danube Delta Reserve and Romanian Black Sea littoral. In general, the types of expected results from scenario analysis by the MAL5 SD sub-models are associated with quantification of agricultural production and associated pollution (sub-model 1) and marine aquaculture stock (sub-model 2) which is directly influenced by the land-based sources pollution. These expected scenario analysis results and their implications can be related to the key overarching frameworks listed in Table 39, and the marine spatial planning project for Romania (MARSPLAN)[27].

Table 39. Types of scenarios that may be testable/tested through the SD modelling in MAL5 and their relations to topics/scenarios in the listed overarching frameworks (European Green Deal topics, Figure 9; SDGs: UN Sustainable Development Goals in Agenda 2030, Figure 10; SSPs: Shared Socioeconomic Pathways, Figure 11; Topics in applicable MSP: Marine Spatial Plan).

Types of scenarios for SD modelling	Indicate if the scenarios can be related to any of the overarching frameworks and briefly to which framework topics/scenarios			
	Topic in European Green Deal	SDGs	SSP scenarios	Topic in MSP
Restoring degraded ecosystems at land and sea by increasing organic farming and biodiversity-rich landscape features on agricultural land	Yes Biodiversity	Yes SDG 14	No	Yes MARSPLAN project
Reducing the use and harmfulness of pesticides, restoring the Danube river and Danube Delta to a free-flowing state	Yes From farm to fork	Yes SDG 6	Yes Sustainability	Yes MARSPLAN project
Planting forest belts	Yes Biodiversity	Yes SDG 13	Yes Sustainability	No
Reduce nutrient losses, while ensuring no deterioration on soil fertility and reduce of fertilizer use	Yes From farm to fork	Yes SDG 12	Yes Sustainability	Yes MARSPLAN project
Investment in education, training and research coupled with increasing seawater temperature effect on the marine aquaculture stock (climate change)	Yes From farm to fork	Yes SDG 6	Yes Sustainability, Population and Education	Yes MARSPLAN project

5.5.5 Data/Model sources and general references

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Online available data for SD sub-model quantification in MAL5:

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16. https://insse.ro/cms/ - collection of data from National Institute for Statistics, Romania
17. http://www.anpa.ro – National Agency for Fishing and Aquaculture

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5.6 Multi-Actor Lab 6. Mar Menor Coastal Lagoon (Western Mediterranean) - Spain

5.6.1 Introduction and problem scope for land-sea SD modelling

The Mar Menor coastal lagoon (135 km^2) is located in the Region of Murcia in South-eastern Spain. The catchment draining into the Mar Menor covers an area of 1.255 km^2 and is mainly covered by intensive irrigated agriculture with horticulture, tree crops and greenhouses, while the coastline is occupied by villages and tourist accommodations (Figure 52).

Figure 52. Cropland area in the Campo de Cartagena near the Mar Menor lagoon.

The different environmental, economic, and socio-cultural activities and interests in the area often compete for scarce resources, affecting especially water quality and quantity and many related ecosystem services. During COASTAL workshops, it has increasingly become clear that although there are opposed interests and trade-offs between diverse activities, there is also a high potential for complementarity, win-win scenarios and development of sustainable business cases based on public-private collaboration, more efficient water use, innovative farming practices, and a transition to sustainable models of tourism, agriculture and renewable energy (Tiller et al., 2019b).

The identification of most effective solutions and possible trade-offs requires careful assessment of system interactions and feedbacks, which is what System Dynamics (SD) model development focuses on, and further explained in following sections.

The large-scale, intensive and highly profitable, irrigated agriculture depends on scarce low quality groundwater, water from inland inter-basin water transfers, and desalinization plants at the coast. Agriculture provides labor and income to the region, but forms a source of excessive nutrients and contamination into the Mar Menor coastal lagoon via surface and groundwater. The resulting poor water quality affects the ecology of the lagoon with severe implications for its potential function for tourism and fisheries (Viaene et al., 2020). There is therefore increasing public pressure on the agriculture sector to shift towards more sustainable farming practices and reducing water and nutrients inputs.

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Potential measures range from the implementation of Nature-Based Solutions (NBS) for nutrient and water retention to prevent floods and further eutrophication of the lagoon to reduced fertilizer use and reduction in the total area covered by agriculture. In addition, there is an appeal to the regional and national governments to develop and apply stricter regulations for fertilizer use and to prevent illegal irrigated areas by forcing compliance. It is also speculated that investments in education and public awareness will further contribute to more balanced policies.

The coastal lagoon forms part of a Specially Protected Area of Mediterranean Importance (SPAMI). Driven by its environmental interest and high biodiversity, crystalline water, excellent swimming and sailing conditions, the Mar Menor is one of the hotspots for tourism in the Region of Murcia. Beside international visitors, the Mar Menor has a very important touristic function for the regional population (1.5 million inhabitants). However, most tourism activities are concentrated in few summer months and urban wastewater also provides an additional pressure on the water quality. It is expected that a decrease in the seasonality of tourists will reduce its environmental impacts and favour synergistic development of coastal and rural tourism. Nevertheless, the decreasing water and environmental quality of the lagoon affects the attractiveness for tourists. As such, the development of the Mar Menor and surrounding areas is strongly influenced by interactions between inland agriculture on the one side, and coastal tourism and fisheries affecting natural ecological values and socioeconomic sustainability on the other side. Consequently, the need to move towards sustainable agriculture, fishery and tourism is increasingly recognized and recently revived strongly due to sudden increase in contamination levels resulting in a strong drop in tourism (Viaene et al., 2020).

Regarding future climate change, the availability of water for irrigation and drinking water for tourism is expected to be further reduced under future climate conditions in the area itself, but also in inland catchments that provide water to the region through Tajo-Segura inter-basin water transfer. It is expected that in the coming years the provision of water through the inter-basin transfer will strongly decrease in order to maintain ecological flows in the Tajo catchment. This means that there will be less water available in the Mar Menor area, affecting agriculture and tourism, and possibly resulting in a higher demand for sea water desalinization and groundwater extraction.

The SD model of the different sectors in the Mar Menor was developed based on the causal loop diagrams (CLD) that were co-created in collaboration with stakeholder during the sectoral and multi-actor workshops (Tiller et al., 2019a and 2019b). The SD model development focuses on modelling system interactions and their response to potential solutions for sustainable development in each of the sectors under current and potential future socioeconomic and climate conditions. The main land-sea interactions considered in the model are (Viaene et al., 2020):

- 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.
- The potential of sustainable land management (SLM) practices in agriculture to reduce fertilizer input and implement nutrient and water retention.

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5.6.2 Quantified SD sub-models

Different sub-models were developed that are linked to simulate dynamic interactions between sectors in the Campo de Cartagena catchment and the Mar Menor lagoon from 1961 until 2070 (Figure 53). Available sub-models, as outlined in Table 40, are:

- Agricultural water balance: This sub-model characterizes 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. Water demand is driven by the expansion of irrigated land areas. This sub-model allows the evaluation of some scenarios in relation to climate change and some regulatory management actions proposed by the regional and national authorities.
- Agricultural nutrients balance: This sub-model focuses on the quantification of the nutrient's export from irrigated agricultural areas to the Mar Menor lagoon based on the amount of fertilization used. It allows the evaluation of scenarios in relation to some potential end-of-pipe solutions, according to the current set of proposed management actions by the regional and national authorities.
- Sectoral development and economic profit: This sub-model reproduces the development of three main sectors involved, i.e. agriculture, tourism and solar photovoltaic facilities. The sub-model assesses the development of each sector together with the number of jobs created and its economic profit and allows simulating the effect of an equitative policy for each sector.
- Mar Menor lagoon degradation: This sub-model simulates the degradation status of the Mar Menor lagoon over time following the input of nitrogen from agricultural sources, which was recognized during the workshops as the main driver of its environmental degradation (Tiller et al., 2019b).
- Coastal-rural recreation potential: This sub-model assesses the influence of the degradation of the Mar Menor lagoon on the coastal recreation potential, as well as the effect of increasing the rural and coastal recreation potential on the tourism growth.
- Social awareness and governance: Given the importance that stakeholders attributed to social environmental awareness and education (Tiller et al., 2019a and 2019b), this sub-model implements two mechanisms that represent social and governance feedbacks in relation to the regulation and development of different sectors that take place in this study area.
- SLM practices: This sub-model quantifies the benefits of implementing two SLM practices, including the decrease in the application of fertilizers and the implementation of vegetation buffers around agricultural fields in order to prevent nutrient export and floods.

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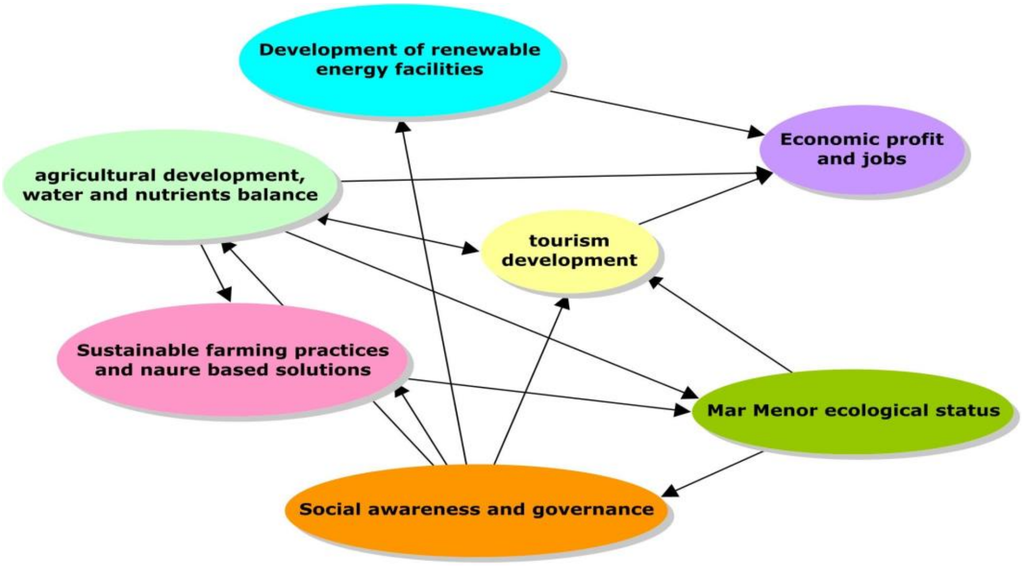

Figure 53. Overview of the topics covered by the MAL6 SD sub-models and their interlinkages.

Table 40. List of developed SD sub-models, their associated problems and their quantification status (fully/partially/not yet quantified) in MAL6.

No.	Title of SD sub-model	Addressed problems	Status of quantification
1	Agricultural water balance	Water scarcity, high demand of water by agriculture; high dependency on Tagus-Segura water transfer; climate change uncertainty; high amount of (illegal) groundwater extraction; desalination of polluted groundwater pumped producing untreated brine wastes	partially quantified
2	Agricultural nutrients balance	Excessive use of fertilizers in irrigated agricultural areas; agricultural nutrients input via surface water and groundwater to the lagoon; illegal irrigated agricultural areas	partially quantified
3	Sectoral development and economic profit	Unbalanced sectoral growth due to lack of social pressure on public administrations and participatory governance; development of agriculture, tourism and renewable energy sectors	partially quantified
4	Mar Menor lagoon degradation	Mar Menor eutrophication status	partially quantified
5	Coastal-rural recreation potential	Interaction between rural and coastal tourism activities and effect of Mar Menor degradation	partially quantified
6	Social awareness and governance	Effect of environmental education on participatory governance	partially quantified
7	Sustainable land management (SLM) practices	Effect of nutrients and soil retention measures	partially quantified

5.6.2.1 Sub-model 1. Agricultural water balance

5.6.2.1.1 Quantified key land-sea interactions and feedback structures in sub-model 1

Given the structural water scarcity in the region, the high amount of groundwater extraction, together with the opening of Tagus-Segura water transfer are the main drivers of the expansion of irrigated agricultural areas. This sub-model characterizes the agricultural water balance in the Mar Menor catchment, which represents around 85% of the total water consumption in this area, and how available water for irrigation

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determines, to a large extent, the potential expansion of irrigated crops. Water demand is driven by the expansion of irrigated land areas. Sub-model 1 includes some scenarios (variables in green color in stock-flow (SF) structure shown in Figure 54) in relation to climate change and some regulatory management actions proposed by the regional and national authorities. Variables in this sub-model were summarized in COASTAL Deliverable 13 – Section 3.6.12 (Viaene et al., 2020) and are also presented here in Table 41 with possibly some updates based on the sub-model progress in MAL6.

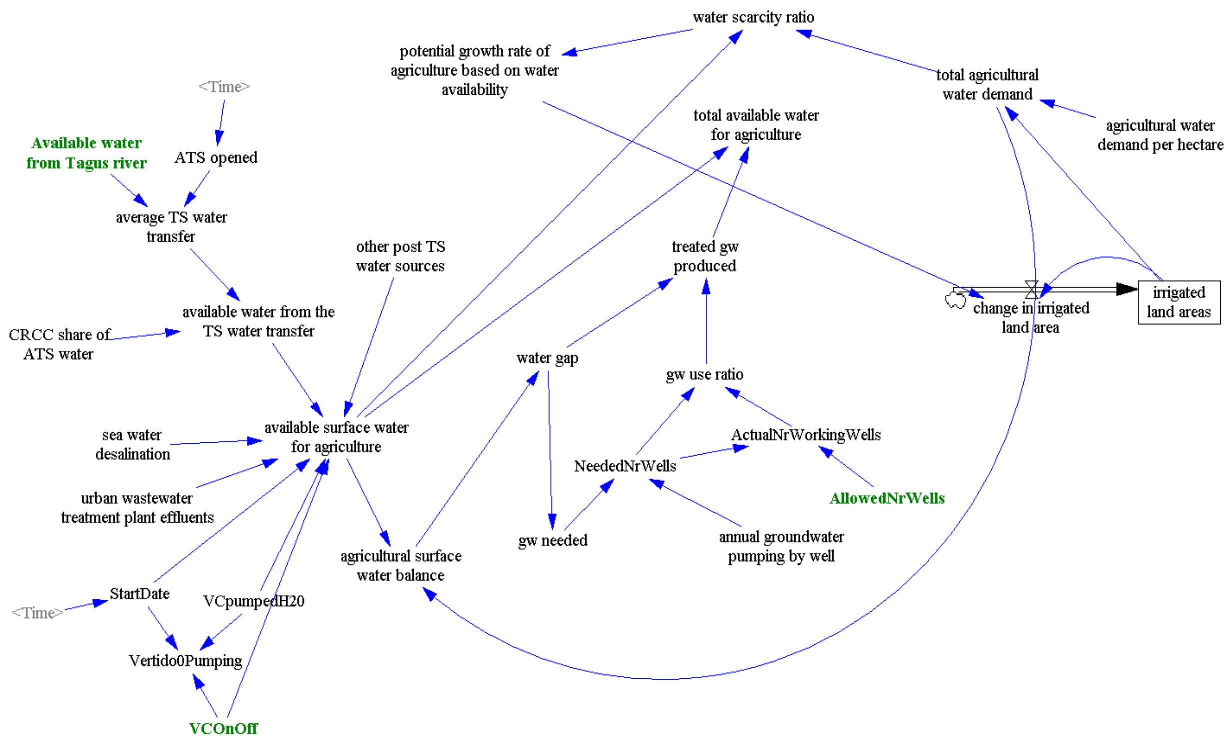

Figure 54. SF structure of SD sub-model 1 in MAL6 developed in Vensim software. Green colored variables represent main scenarios (Viaene et al., 2020).

Table 41. Main variables in SD sub-model 1 for MAL6 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
ActualNrWorkingWells	Count	O	A	Number of active wells
agricultural surface water balance	Hm3	O	A	It corresponds to the available surface water for agriculture (plus the VC water pumped) minus the total agricultural water demand
agricultural water demand per hectare	Hm3/Ha*year	I	A	Average agricultural water demand per hectare and per year
AllowedNrWells	Count	I	A	This variable represents a scenario in which the number of wells is limited by legislation
annual groundwater pumping by well	hm3/well	I	A	Average annual groundwater pumping by well
ATS opened	Dimensionless	B	A	A switcher that opens the Tagus-Segura water transfer in 1979

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available surface water for agriculture	Hm3/year	O	A	The sum of all surface water sources
Available water from Tagus river	Hm3/year	L	A	The yearly average amount of water that has been transferred or is predicted to be transferred based on CC scenarios.
available water from the TS water transfer	Hm3/year	L	A	The water diverted to the Campo de Cartagena from the Tagus-Segura aqueduct
average TS water transfer	Hm3/year	L	A	The water actually transferred as long as the aqueduct opened
CRCC share of ATS	percentage	I	A	The percentage of water that is assigned to the Comunidad de Regantes del Campo de Cartagena
gw needed	Hm3/year	O	A	Total amount of groundwater needed to meet the agricultural water demand
gw use ratio	Percentage	O	A	The fraction of groundwater needed that is actually pumped based on the number of working wells
NeededNrWells	Count	O	A	The number of wells needed in order to pump all the groundwater demanded
other post TS water sources	Hm3/year	I	A	Additional sources of surface water available for the Campo de Cartagena
sea water desalination	Hm3/year	I	A	Sea water desalinated that serves as an input for the agricultural water demand
total agricultural water demand	Hm3/year	O	A	Total agricultural water demand
total available water for agriculture	Hm3/year	O	A	The sum of the available surface water for agriculture and the groundwater pumped
treated gw produced	Hm3/year	O	A	Total amount
urban wastewater treatment plant effluents	Hm3	I	A	urban wastewater treatment plant effluents that serve as an input for the agricultural water demand
VCpumpedH20	Hm3/year	I	A	Water extracted from the aquifer by the Vertido Cero Plan
water gap	Hm3/year	O	A	The agricultural water needed not met by the surface water sources
water scarcity ratio	Percentage	O	A	The fraction of the total agricultural water demand that is not met by the available surface water for agriculture

5.6.2.1.2 Outline of quantitative information to support sub-model 1

We included all variables that determine water demand from agriculture and water supply from all different sources. Groundwater extraction is calculated based on water deficit. ‘ATS opened’ is a binary variable that becomes 1 in 1979 when Tagus-Segura (TS) water transfer was opened. The available water from TS water transfer is obtained by multiplying average TS water transfer (330 hm^3/year) by the officially established share of ATS water for the ‘Comunidad de Regantes del Campo de Cartagena’ (CRCC) of 17% (Tecnologías y Servicios Agrarios, S.A. (TRAGSATEC), 2019). Available water from Tagus river is constant for the historical period covered by the model (resulting in a yearly average of 56.1 hm^3/year) 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

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projections and how these change the water availability for transfer between Tajo and Segura catchments (Pellicer-Martínez and Martínez-Paz, 2018).

The available surface water for agriculture is the sum of: (1) the available water from TS water transfer, (2) other post TS water sources (11 hm^3/year), (3) the sea water desalination (8.2 hm^3/year), (4) urban wastewater treatment plant effluents (21.5 hm^3/year) and eventually (5) the additional water extracted from the aquifer if Vertido Cero (VC) Plan starts (VCpumpedH20) (TRAGSATEC, 2019). The 'VC plan' might be eventually launched by the National government and aims to extract polluted water from the aquifer, clean it from salt and nitrogen, and give it back to farmers for irrigation at an agreed price. In the sub-model 1, when this scenario is activated, the amount of surface water available for agriculture is increased by the expected amount of water pumped (12 hm^3/year) (TRAGSATEC, 2019).

The total agricultural water demand is calculated by multiplying the agricultural water demand per hectare (0.004 hm^3/ha) (TRAGSATEC, 2019) by the irrigated land areas (in hectares). 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. Needed groundwater (gw) 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 sub-model considers an average value for all wells as 0.15 hm^3) (Soto García et al., 2014). 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 sub-model). The gw use ratio is computed by dividing the ActualNrWorkingWells by the NeededNrWells.

Total available water for agriculture is sum of the available surface water for agriculture and treated gw produced. It is not used in this sub-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.

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 (see sub-model 3), 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 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.

This sub-model will be updated in terms of variables, structure, equations and/or data, according to the outcomes of the expert interviews and the second multi-actor workshop that are being carried out at the time of the report preparation.

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5.6.2.2 Sub-model 2. Agricultural nutrients balance

5.6.2.2.1 Quantified key land-sea interactions and feedback structures in sub-model 2

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. This sub-model 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 color; Figure 55) 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 as represented in the MAL workshops. Variables in this sub-model were summarized in COASTAL Deliverable 13 – Section 3.6.12 (Viaene et al., 2020) and are also presented here in Table 42 with possibly some updates based on the sub-model progress in MAL6.

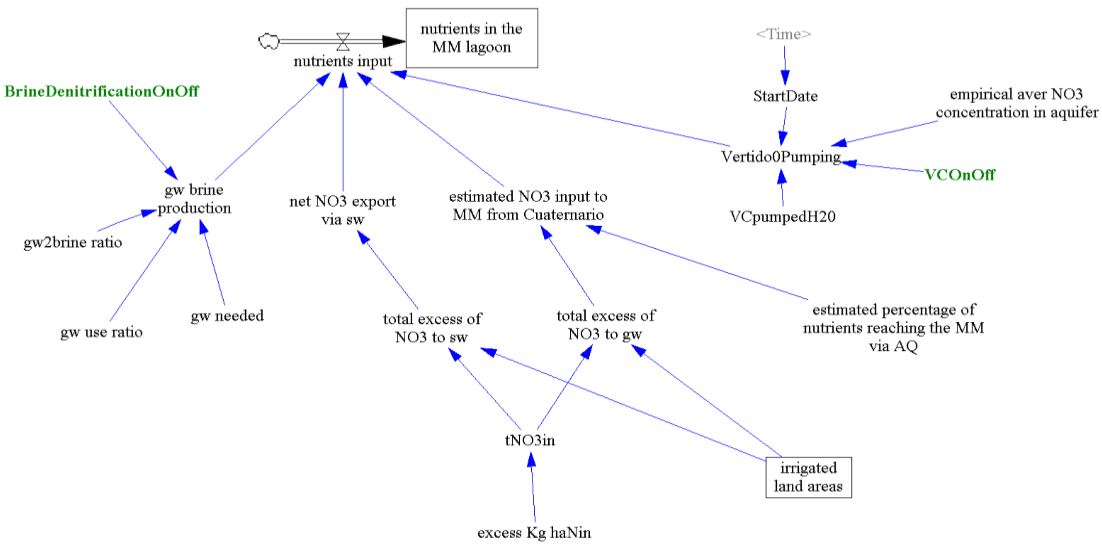

Figure 55. SF structure of SD sub-model 2 in MAL6 developed in Vensim software. Green colored variables represent main scenarios (Viaene et al., 2020).

Table 42. Main variables in SD sub-model 2 for MAL6 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant, MM: Mar Menor).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
BrineDenitrificationOnOff	Dimensionless	I	A	Binary variable acting as a switch to (de)activate the brine denitrification scenario
empirical aver NO3 concentration in aquifer	Ton/Hm3	I	A	Empirically measured average of NO3 concentration in the Cuaternario aquifer
estimated NO3 input to MM from Cuaternario	Tons/year		A	Final amount of nutrient inputs to the Mar Menor via the Cuaternario aquifer
estimated percentage of nutrients reaching the MM via AQ	Percentage	I	A	Estimated percentage of nutrients reaching the Mar Menor via the Cuaternario aquifer
excess Kg haNin	Kg/Ha*year	O	A	Nitrogen leached in agricultural fields

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gw brine production	Tons/year	O	A	Total amount of nutrients from brine exported to the Mar Menor lagoon
gw2brine ratio	percentage	I	A	Percentage of usable water contained in the groundwater pumped from the aquifer
nutrients input	Tons/year	O	F	Total nutrient inputs to the Mar Menor lagoon
tNO3in	Tons/Ha*year	O	A	Nitrate leached in agricultural fields
total excess of NO3 to gw	Tons/year	O	A	Total amount of nutrients leached to groundwater
total excess of NO3 to sw	Tons/year	O	A	Total amount of nutrients leached to surface water
VCOnOff	Dimensionless	I	A	Binary variable to switch on or off the Vertido Cero scenario
Vertido0Pumping	Tons/year	O	A	Tons of nutrients extracted from the aquifer by the Vertido Cero water pumping

5.6.2.2.2 Outline of quantitative information to support sub-model 2

There are three main sources of agricultural nutrient inputs to the Mar Menor lagoon, i.e. nutrients contained in:

(1) surface water (sw) runoff (in tons):

$$\begin{aligned} net\ NO3\ export\ via\ sw \\ &= total\ excess\ of\ NO3\ to\ sw \\ &- (total\ excess\ of\ NO3\ to\ sw \\ &\times yearly\ effectiveness\ in\ nutrient\ reduction\ of\ Vegetation\ Buffers \\ &\times Vegetation\ Buffers\ implementation\ level) \end{aligned} \tag{63}$$

(2) groundwater (in tons):

$$\begin{aligned} estimated\ NO3\ input\ to\ MM\ from\ Cuaternario \\ &= total\ excess\ of\ NO3\ to\ gw \\ &\times estimated\ percentage\ of\ nutrients\ reaching\ the\ Mar\ Menor\ via\ AQ \end{aligned} \tag{64}$$

(3) brine wastes (in tons) resulting from polluted water being pumped from the aquifer and then treated to remove excessive salts and nutrients:

$$\begin{aligned} gw\ brine\ production \\ &= gw\ needed \times gw\ use\ ratio \times gw2brine\ ratio\ \times 0.5 \\ &\times (1 - BrineDenitrificationOnOff) \end{aligned} \tag{65}$$

This sub-model is primarily driven by the excessive use of fertilizers per hectare (excess Kg haNin; 40 Kg/ha) (TRAGSATEC, 2019) 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 groundwater and surface water, as 85% and 15% respectively (TRAGSATEC, 2019). 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 lagoon via the aquifer (AQ) of 15% based on literature data (TRAGSATEC, 2019), which is multiplied by the total excess of NO3 to gw and gives the estimated NO3 input to Mar Menor 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 reduced by the effect of

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SLM practices that could be implemented as a scenario, and is explained in the section corresponding to sub-model 7.

Since the aquifer is polluted with nutrients, when groundwater is pumped to be used for irrigation, around 50% 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) that is 25% (TRAGSATEC, 2019). 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; see sub-model 1) and the empirical average NO3 concentration measured in the aquifer (186 t/hm^3) (TRAGSATEC, 2019).

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

5.6.2.3 Sub-model 3. Sectoral development and economic profit

5.6.2.3.1 Quantified key land-sea interactions and feedback structures in sub-model 3

This sub-model tries to reproduce and predict development of the three key sectors, i.e. agriculture, tourism and solar photovoltaic facilities, in the study area. The sub-model includes the development of each sector together with the number of jobs created and its economic profit. Variables in this sub-model were summarized in COASTAL Deliverable 13 – Section 3.6.12 (Viaene et al., 2020) and are also presented here in Table 43 with possibly some updates based on the sub-model progress in MAL6.

Table 43. Main variables in SD sub-model 3 for MAL6 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
agricultural development	Percentage	O	A	Final agricultural development
agricultural net economic margin based on hectares	EUR	O	A	Total net profit of agricultural producers
Agricultural production value based on hectares	EUR	O	A	Total agricultural production value
Agricultural total export value	EUR	O	A	Total agricultural export value

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Average number of overnights per tourist a year	Number of overnights/tourist*year	I	A	Average number of overnights per tourist a year
change in irrigated land area	Ha/year	L	F	Yearly change in irrigated land area
Daily average expenditure per tourist	EUR/person/day	I	A	Daily average expenditure per tourist
direct agriculture employees	Count	O	A	Total number of direct agriculture employees
field workers	Count	O	A	Total number of field workers
indirect employees	Count	O	A	Total number of indirect agriculture employees
initial MW installed	Mw	L	A	Initial amount of renewable energy power installed
Initial nr of tourists	Count	I	A	Initial number of tourists
irrigated land areas	Ha	O	S	Extent of irrigated agricultural areas
new RE installation	Mw	L	F	Change in renewable energy facilities power installed
number of employees in agriculture	Count	O	A	Total number of employees in agriculture
number of employees in tourism	Count	O	A	Total number of employees in tourism
number of jobs for installing RE facilities	Count	O	A	Total number of employees for the installation of photovoltaic renewable energy facilities
number of jobs in RE facilities	Count	O	A	Total number
observed growth rate of agriculture	percentage	I	A	Historical rate of agricultural growth rate
observed growth rate of REs	percentage	I	A	Historical rate of renewable energy power growth rate
observed growth rate of tourism	percentage	I	A	Historical rate of tourism growth rate
potential growth rate of agriculture based on water availability	percentage	L	A	The fraction of the total agricultural water demand that is met by the available surface water for agriculture
RE installed	Mw	O	S	Total power of photovoltaic energy installed
Total agricultural value	EUR	O	A	The sum of the agricultural production value and the agricultural
Total jobs related to RE facilities	Count	O	A	Sum of the number of jobs for installing and maintenance of photovoltaic energy facilities
tourist growth	Count/year	L	F	Yearly Change in tourists
warehouse workers	Count	O	A	Number of warehouse agricultural employees
yearly economic value of tourism based on overnights	EUR	O	A	Yearly economic value of tourism
yearly tourists	Count	O	S	Total number of yearly tourists

5.6.2.3.2 Outline of quantitative information to support sub-model 3

In relation to agricultural development (Figure 56), 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

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of irrigated land areas and (3) the agricultural development (percentage), which depends on the historical observed growth rate of agriculture of 6% in the study area (Carreño et al., 2015) plus other variables that will be explained in the section about the sub-model 6. 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 (0.5 employees per hectare) and a further characterization of the job type is included, such as direct (85%) and indirect (15%) agriculture employees (CHS, 2015). From the direct workers and estimation of the number of warehouse (30%) and field (70%) workers are also calculated (CHS, 2015). On the other hand, the agricultural production value (7,150 EUR/ha) and net economic margin based on hectares (4,700 EUR/ha) are calculated based on the extent of irrigated land areas (CHS, 2015). Then, the agricultural total export value corresponds to 2.6 times the agricultural production value based on hectares and the total agricultural value is finally computed as the sum of the production and export values (CHS, 2015).

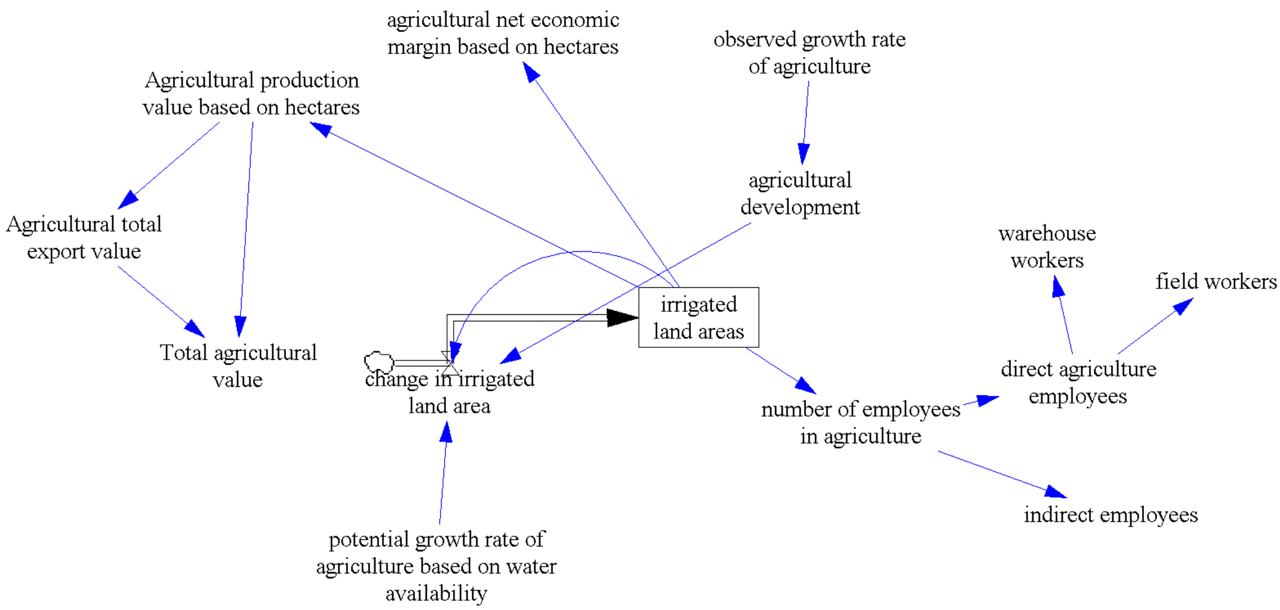

Figure 56. SF structure of SD sub-model 3 related to agricultural development in MAL6 developed in Vensim software (Viaene et al., 2020).

In relation to tourism development (Figure 57), 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 (6.5%) and the current number of yearly tourists of around 200,000 in high season (ECONET, 2020a). The number of employees in tourism is calculated based on the yearly tourists (0.01 employees per tourist) (ECONET, 2020a). 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 (3 overnights/tourist) and the daily average expenditure per tourist (57 EUR/tourist/day) (Arroyo Mompeán and Vegas Juez, 2019). 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.

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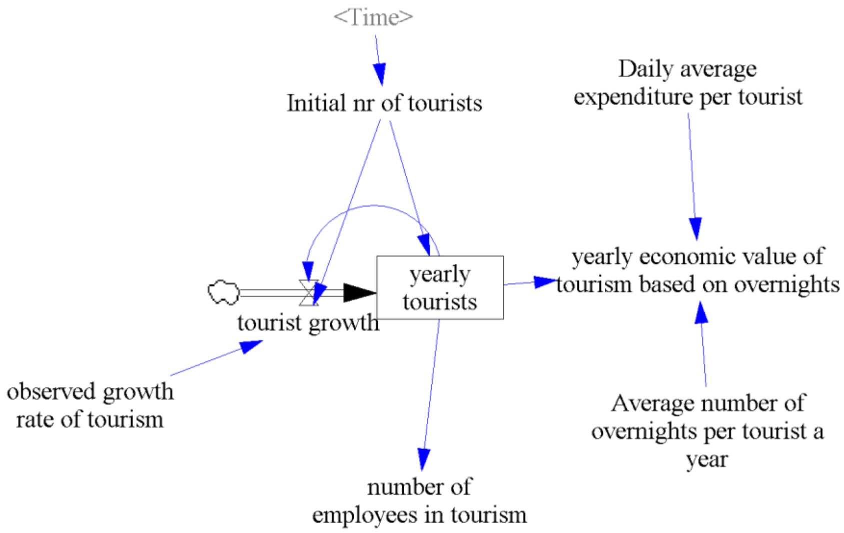

Figure 57. SF structure of SD sub-model 3 related to tourism development in MAL6 developed in Vensim software (Viaene et al., 2020).

In relation to the development of photovoltaic energy facilities (Figure 58), 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 (2.8%) (ECONET, 2020b). 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 (not yet quantified). The number of total jobs related to RE facilities is then calculated as the sum of both job types.

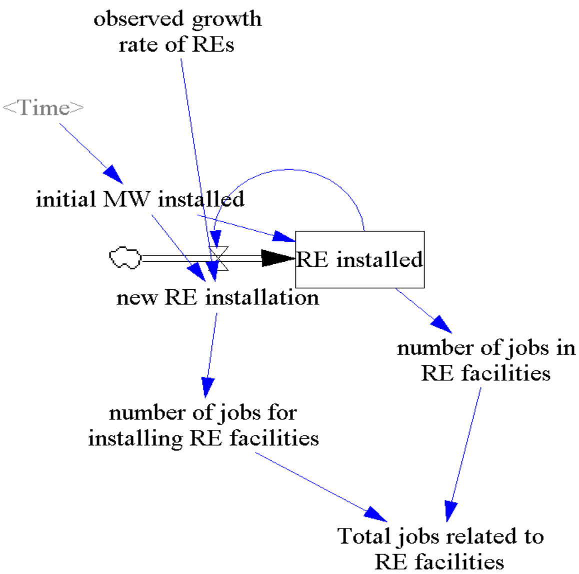

Figure 58. SF structure of SD sub-model 3 related to renewable energy development in MAL6 developed in Vensim software (Viaene et al., 2020).

Sub-model 3 will be updated in terms of variables, structure, equations and/or data, according to the outcomes of the expert interviews and the second multi-actor workshop that are being carried out at the time of the report preparation.

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5.6.2.4 Sub-model 4. Mar Menor degradation

5.6.2.4.1 Quantified key land-sea interactions and feedback structures in sub-model 4

Land-sea system interactions in this sub-model are related to the degradation and biodiversity loss in the lagoon and associated wetlands around the Mar Menor lagoon due to eutrophication (Figure 59). Based on the limited scientific knowledge about the process of ecosystem collapse in the lagoon, this sub-model tries to exemplify the degradation of the Mar Menor lagoon linked to long-term inputs of nutrients observed and modelled in sub-model 2. Variables in sub-model 4 were summarized in COASTAL Deliverable 13 – Section 3.6.12 (Viaene et al., 2020) and are also presented here in Table 44 with possibly some updates based on the sub-model progress in MAL6.

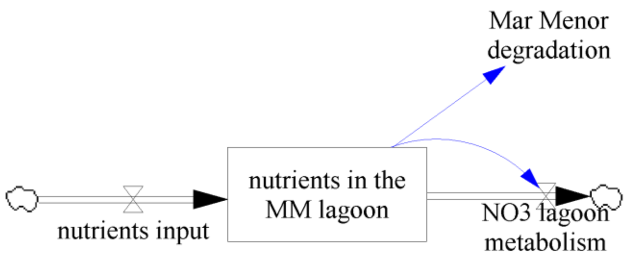

Figure 59. SF structure of SD sub-model 4 in MAL6 developed in Vensim software (Viaene et al., 2020).

Table 44. Main variables in SD sub-model 4 for MAL6 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant, MM: Mar Menor).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
Mar Menor degradation	fraction	O	A	Degradation status of the Mar Menor lagoon
NO3 lagoon metabolism	Tons/year	L	F	Amount of nutrient being processed by the Mar Menor lagoon ecosystem
nutrients in the MM lagoon	Tons	O	S	Total amount of nutrients in the Mar Menor lagoon

5.6.2.4.2 Outline of quantitative information to support sub-model 4

One of the main challenges was to quantify degradation of the Mar Menor lagoon over time since it went through a rapid and recurrent ecological collapse starting in 2016. The amount and complexity of ecological processes occurring at different scales and realms within the lagoon made it impractical to develop an accurate model of ecological processes within the lagoon. Therefore, we had to simplify the model equations and calibrate the model outputs based on observed patterns and identify the most important causes and drivers.

The nutrients in the Mar Menor lagoon are accumulated over time and are calculated as the difference between the nutrients input (explained in the section corresponding to sub-model 2) and the NO3 lagoon metabolism, which is capable of processing 10% of the total nutrients accumulated (Comité de Asesoramiento Científico del Mar Menor, 2017). The Mar Menor degradation goes from 0 to 1, from undegraded to degraded status, is calculated using an exponential function to match the observed degradation status over time as follows:

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$$Mar\ Menor\ degradation = \frac{1}{1 + exp(-0.0005 \times (nutrients\ in\ the\ lagoon - 15000))} \tag{66}$$

Sub-model 4 will be updated in terms of variables, structure, equations and/or data, according to the outcomes of the expert interviews and the second multi-actor workshop that are being carried out at the time of the report preparation.

5.6.2.5 Sub-model 5. Coastal-rural recreation potential

5.6.2.5.1 Quantified key land-sea interactions and feedback structures in sub-model 5

Land-sea system interactions in this sub-model are related to the decrease in recreational opportunities for tourists and for local populations living around the Mar Menor lagoon due to poor water quality. This sub-model assesses the influence of the degradation of the Mar Menor lagoon in the coastal recreation potential, as well as the effect of increasing the rural and coastal recreation potential on the tourism growth. Variables in this sub-model were summarized in COASTAL Deliverable 13 – Section 3.6.12 (Viaene et al., 2020) and are also presented here in Table 45 with possibly some updates based on the sub-model progress in MAL6.

Table 45. Main variables in SD sub-model 5 for MAL6 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
coastal recreation potential	dimensionless	I	A	Relative coastal recreation potential value
coastal rural recreation potential	dimensionless	O	A	Sum of rural and coastal relative recreation values
rural recreation potential	percentage	I	A	Relative rural recreation potential value

5.6.2.5.2 Outline of quantitative information to support sub-model 5

The tourism growth variable, primarily depending on the observed growth of tourism, as explained in sub-model 3, also accounts for the coastal rural recreation potential, which is sum of the coastal and rural recreation potential. The rural recreation potential is an input variable that goes from 0 (no recreation value) to 1 (full recreation value), defaulting in 0, and can be increased when the number of rural ecotourism activities increases (or is expected to increase), which is not part of the model. The coastal recreation potential is zero when the Mar Menor degradation also is high (> 0.98) and 1 otherwise (Figure 60). Sub-model 5 will be updated in terms of variables, structure, equations and/or data, according to the outcomes of the expert interviews and the second multi-actor workshop that are being carried out at the time of the report preparation.

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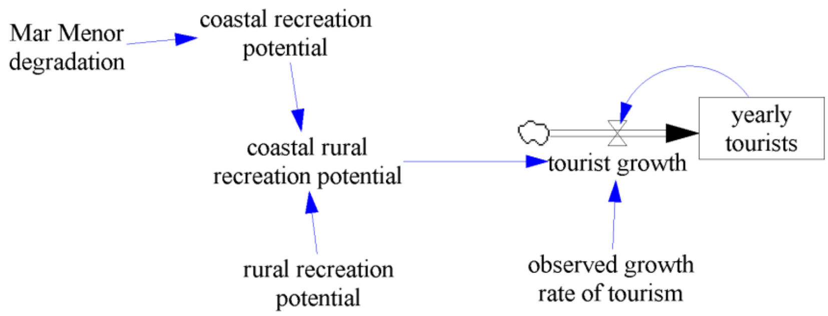

Figure 60. SF structure of SD sub-model 5 in MAL6 developed in Vensim software (Viaene et al., 2020).

5.6.2.6 Sub-model 6. Social awareness and governance

5.6.2.6.1 Quantified key land-sea interactions and feedback structures in sub-model 6

Social awareness and participatory governance are crucial in order to overcome current ecological crisis while promoting a sustainable economic development. This sub-model implements two mechanisms that represent social and governance feedbacks in relation to the regulation and development of different sectors that take place in the study area, and particularly of the agricultural sector (Figure 61). Variables in this sub-model were summarized in COASTAL Deliverable 13 – Section 3.6.12 (Viaene et al., 2020) and are also presented here in Table 46 with possibly some updates based on the sub-model progress in MAL6.

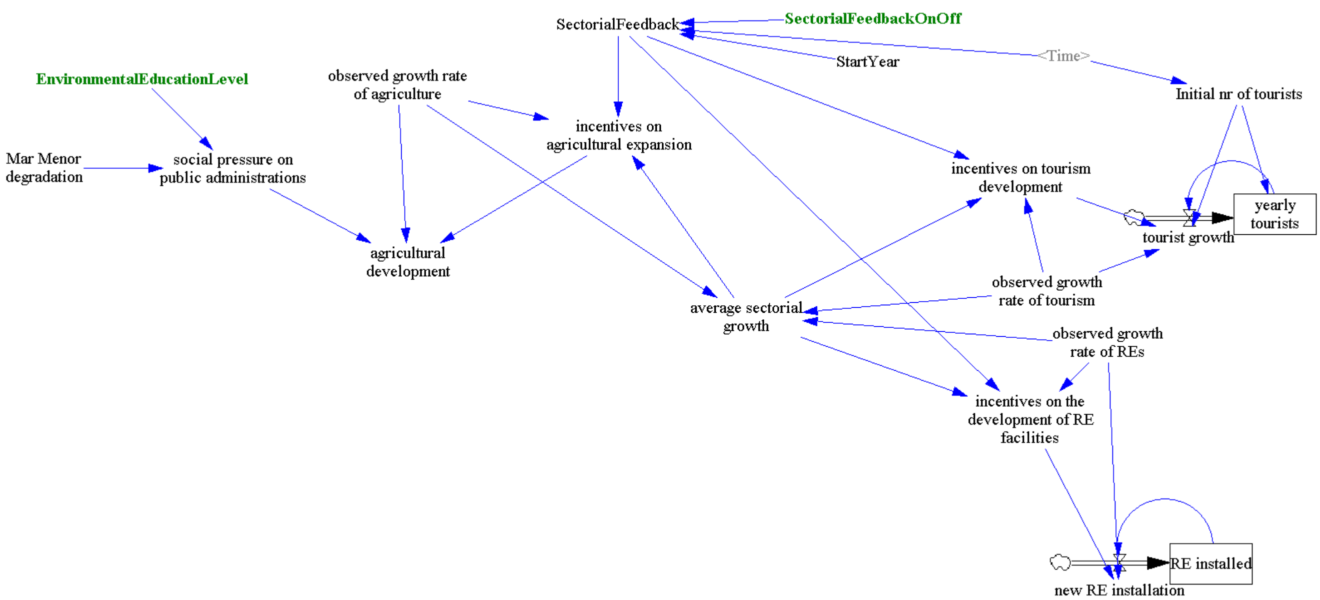

Figure 61. SF structure of SD sub-model 6 in MAL6 developed in Vensim software. Green colored variables represent main scenarios (Viaene et al., 2020).

Table 46. Main variables in SD sub-model 6 for MAL6 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
average sectorial growth	percentage	O		Average sectorial growth
EnvironmentalEducationLevel	dimensionless ranking	I	A	Environmental education level of the local populations

incentives on agricultural expansion	Percentage	L	A	Positive or negative incentives by public administrations in relation to the development of the agricultural sector
incentives on the development of RE facilities	Percentage	L	A	Positive or negative incentives by public administrations in relation to the development of the photovoltaic renewable energy sector
SectorialFeedback	Dimensionless	B	A	Binary variable as a switch to (de)activate the sectorial feedback scenario in a specific year
SectorialFeedbackOn Off	Dimensionless	I	A	Binary variable as a switch to (de)activate the sectorial feedback scenario
social pressure on public administrations	Percentage	O	A	Relative pressure exerted by an environmentally-aware society on the public administration

5.6.2.6.2 Outline of quantitative information to support sub-model 6

The agricultural development variable, primarily a function of the observed growth rate of agriculture, as explained in sub-model 3, is also defined as dependent on the social pressure on public administrations, which is calculated using a response curve function based on the Mar Menor lagoon degradation weighted by the environmental education level scenario (EnvironmentalEducationLevel; from 0 to 1). Environmental education level is an input variable that goes from 0 (no environmental education level) to 1 (full environmental education level), defaulting in 0, and can be increased when the number of environmental education activities increases (or is expected to increase), which is not part of the model. On the other hand, a governance feedback scenario as a binary variable with 0 or 1 value is included in relation to the regulation and development of 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/renewable energy development as a function of the average sectorial growth. This latter variable is calculated taking the average of all the sectorial observed growth values (see sub-model 3). 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 (quantified as the average sectoral growth minus the observed growth of the respective sector) which are added to the observed growth value of the sector.
Sub-model 6 will be updated in terms of variables, structure, equations and/or data, according to the outcomes of the expert interviews and the second multi-actor workshop that are being carried out at the time of the report preparation.

5.6.2.7 Sub-model 7. Sustainable land management practices

5.6.2.7.1 Quantified key land-sea interactions and feedback structures in sub-model 7

SLM practices in agriculture, such as a decrease in 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 and therefore are included in this sub-model. We have started the quantification of the benefits of implementing two SLM practices in our case study, including decrease in application of fertilizers and implementation of vegetation buffers around agricultural fields (Figure 62). Variables in this sub-model were

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summarized in COASTAL Deliverable 13 – Section 3.6.12 (Viaene et al., 2020) and are also presented here in Table 47 with possibly some updates based on the sub-model progress in MAL6.

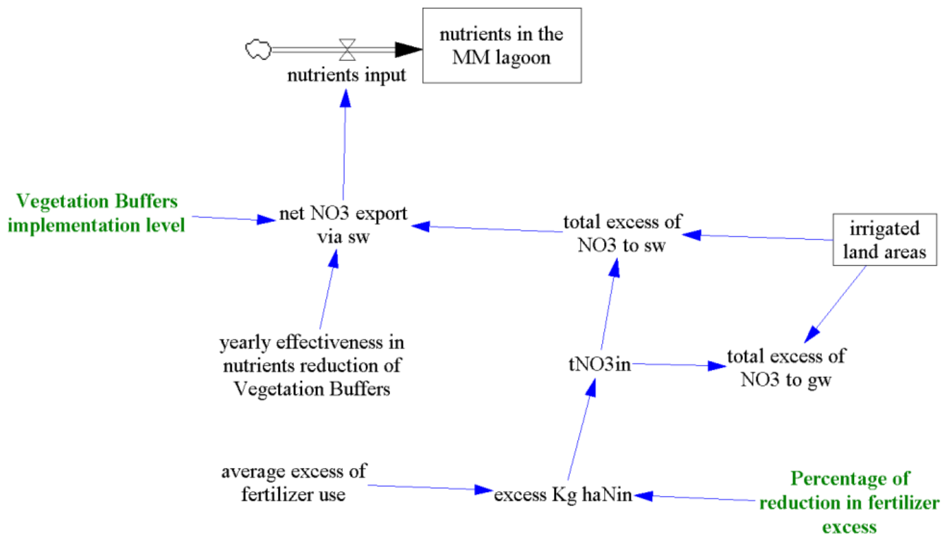

Figure 62. SF structure of SD sub-model 7 in MAL6 developed in Vensim software. Green colored variables represent main scenarios (Viaene et al., 2020).

Table 47. Main variables in SD sub-model 7 for MAL6 (I: input, O: output/indicator, L: limiting variable, B: boundary condition, D: driver, S: stock, F: flow/rate, A: auxiliary, Lu: look-up, C: constant).

Name	Unit	Role (I, O, L, B, D)	SD (S, F, A, Lu, C)	Definition
average excess of fertilizer use	Kg N/ha*year	I	A	Average excess of Nitrogen (fertilizer) use
net NO3 export via sw	Tons/year	O	A	Final amount of nutrient inputs reaching the Mar Menor via surface water once vegetation buffers have been implemented
Percentage of reduction in fertilizer excess	percentage	I	A	Scenario of percentage of reduction in fertilizer excess
Vegetation Buffers implementation level	percentage	I	A	Percentage of irrigated agricultural areas which have implemented vegetation buffers
yearly effectiveness in nutrients reduction of Vegetation Buffers	percentage	I	A	Average percentage of yearly nutrients reduction of vegetation buffers

5.6.2.7.2 Outline of quantitative information to support sub-model 7

The excess Kg haNin, explained as part of sub-model 2, is influenced by the average excess of fertilizer use (Kg/ha of Nitrogen input) and weighted by a scenario based on the percentage 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, ranging from a scenario with no vegetation buffers to full implementation of vegetation buffers) 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 of 40% (Rey Benayas et al., 2017). Sub-model 7 will be updated in terms of variables,

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structure, equations and/or data, according to the outcomes of the expert interviews and the second multi-actor workshop that are being carried out at the time of the report preparation.

5.6.3 Synthetic reflection on the quantification process for the different SD sub-models

We use annual average values in the corresponding sub-models because the main goal of our modelling is not to quantify in detail, for example, water and nutrient flows in the study area but to identify coastal and rural sectoral interactions in order to propose sustainable development solutions. Water and nutrient budgets in sub-models are needed as part of the overall SD model, but they are not intended to replace existing spatial hydrological and nutrient models and therefore we used field and model output literature data to feed our SD sub-models. On the other hand, using yearly time series would require including many more variables in the model, making it more complex, to be able to predict values for each single year in the future, which is also not our main goal. Our stakeholders are rather interested in possible trends and gradual transitions, and would not be able to grasp a very complex model structure. Assessing trends also avoids bringing too much attention and critics in the model structure and helps focus on consensus solutions among stakeholders based on key socio-economic and ecological variables as well as land sea interactions of multiple sectors.

The sub-models will be updated in terms of variables, structure, equations and/or data, according to the outcomes of the expert interviews and the second multi-actor workshop that are being carried out at the time of the report preparation. The main issue we faced was due to different reported values for variables measured on the field related to the water and nutrient balance sub-models (sub-models 1 and 2). We finally solved this by using the latest available governmental and scientific data. Expert interviews are also being conducted to decide on the most reliable data sources. The sensitivity analysis foreseen as part of the SD model testing will also help to further asses the implications of the selection of different data sources. The fact that we use mean annual values also helped decreasing the uncertainty in selecting data coming from different studies because average annual values were usually closer to each other. We set the time period of the study to start before Tagus-Segura water transfer was opened to be able to assess its influence and to test the robustness of the model under contrasting scenarios.

5.6.4 Plan for scenario analysis using the SD sub-models

The ultimate goal of SD modelling under development is to support and guide transitions to a future vision developed by 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 (Akinsete et al., 2020). Developed sub-models highlight the relationships among different topics focused for SD modelling. All three economic sectors (agriculture, tourism, and photovoltaic renewable energy) contribute to the total economic profit and jobs in the study area. The Mar Menor ecological status is influenced by agricultural development via water and nutrient inputs and implementation of SLM practices and NBS. On the other hand, ecological status of the lagoon affects social awareness and governance, which in turn might lead to the adoption of SLM practices and implementation of NBS, and regulate the development of different economic sectors. Besides, there is a clear synergy between agriculture and tourism sectors via promoting agrotourism activities.

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The Mar Menor degradation indirectly affects tourism growth via recreation potential, as well as social pressure on public administrations, which in turn negatively affects agricultural development. Besides, 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, increase in agricultural water demand also increases the groundwater needed, thereby producing brine wastes and more nutrient inputs to the lagoon. Social pressure on public administrations and the implications for agricultural and tourism growth potential are central in the effectiveness of this feedback mechanism. Table 48 outlines various scenarios that can be tested by SD sub-models for MAL6 and their potential relation to the key overarching frameworks highlighted in this table.

Table 48. Types of scenarios that may be testable/tested through the SD modelling in MAL6 and their relations to topics/scenarios in the listed overarching frameworks (European Green Deal topics, Figure 9; SDGs: UN Sustainable Development Goals in Agenda 2030, Figure 10; SSPs: Shared Socioeconomic Pathways, Figure 11; Topics in applicable MSP: Marine Spatial Plan).

Types of scenarios for SD modelling	Indicate if the scenarios can be related to any of the overarching frameworks and briefly to which framework topics/scenarios			
	Topic in European Green Deal	SDGs	SSP scenarios	Topic in MSP
Water pumping from the aquifer to extract pollutants and provide additional irrigation water (Vertido Cero Plan)	Yes Eliminating Pollution	Yes SDGs 6, 13, 14	Yes Any scenario through technological development	No
Limitation in the number of groundwater wells	Yes Protecting Nature, Eliminating Pollution	Yes SDGs 6, 13, 14	Yes Any scenario through land-use	No
Implementation of nature based solutions related to agricultural areas, such as vegetation buffers	Yes Nature-based solutions (NBS)	Yes SDGs 6, 14, 15	Yes Any scenario	No
Promotion of environmental education among local populations	Yes	Yes SDGs 6, 14, 15	Yes Any scenario	No
Government control on sectorial growth (participatory governance)	Yes	Yes SDGs 6, 11, 14	Yes Any scenario	No
Enforcement of decrease in the application of fertilizers	Yes Protecting Nature, Eliminating Pollution, From Farm to Fork	Yes SDGs 6, 14, 15	Yes Any scenario through technological development	No
Implementation of brine denitrification technologies	Yes Eliminating Pollution	Yes SDGs 6, 14, 15	Yes Any scenario through technological development	No
Effect of the implementation of solar photovoltaic facilities in job availability	Yes Climate Pact/Law	Yes SDGs 6, 11, 14	Yes Any scenario through technological development	No
Effect on water availability of a decrease in water transfer from Tagus-Segura transfer driven by climate change (or by reducing the water transfer)	Yes Protecting Nature	Yes SDGs 6, 13, 14	Yes Any scenario through RCP-climate scenario relations	No

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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	Yes Climate Pact/Law	Yes SDGs 6, 13, 14	Yes Any scenario through RCP-climate scenario relations	No

5.6.5 Data/Model sources and general references

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