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COASTAL
Collaborative Land-Sea Integration Platform

Deliverable D15

Generic Tools for Business & Policy Analysis – v 1.0

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COASTAL: Collaborative Land and Sea Integration Platform - Co-creating evidence-based business roadmaps and policy solutions for enhancing coastal-rural collaboration and synergies in Europe focusing on economic growth, spatial planning and environmental protection. Project timeframe: 01/05/2018 - 30/04/2022

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ABBREVIATIONS

CAP - Common Agricultural Policy

DG AGI - Directorate-General for Agriculture and Rural Development

DG-EMPL - Directorate-General for Employment, Social Affairs and Inclusion

DG-ENER - Directorate-General for Energy

DG ENV - Directorate General for Environment

DG-GROW - Directorate-General for Internal Market, Industry, Entrepreneurship, and SMEs

DG MARE - Directorate-General for Maritime Affairs and Fisheries

DG REGIO - Directorate-General for Regional Policy and Urban Affairs

EIP-AGRI – European Innovation Partnership for Agricultural productivity and Sustainability

ENRD - EU Network for Rural Development

M – month

MA – multi-actor

MAL – Multi-Actor Lab

MS – Milestone

MSFD – Marine Strategy Framework Directive

RD – rural development

SAB – Scientific Advisory Board

SD – System Dynamics

SDG – Sustainable Development Goal

SF - Stock Flow

WFD – Water Framework Directive

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1. INTRODUCTION

System Dynamics (Sterman, 2000) was selected as the integrative framework based on the graphical transparency of this type of modelling, the direct translation of problems into model structures, consideration of systemic limitations, appropriateness for including human and social aspects directly in the models, and the limited computational requirements – making these models particularly useful for interactive use by and with stakeholders. Systems Dynamics (SD), and in particular stock-flow modelling, been widely used since the 1950s for problem analysis in applications ranging from logistics, control management, engineering and financial management to public policy (Crolla and Cao, 2012; Ghaffarzadegan et al., 2011; Nair and Rodrigues, 2013; Wolstenholme, 19!3) . By nature, stock-flow modelling is strongly problem-driven and an SD-based modelling approach is used to avoid modelling the system 'as a whole', if this can be avoided. Clients or 'problem owners' and business analysts interact to create mental models or 'mind maps' clarifying the problem at hand and defining the way the problem(s) are connected to specific policy or management indicators and potential solutions. It can be used, for example, to explain why certain start-up businesses fail, whereas others suceed under similar circumstances; or why the short-term and long-term impacts of strategic decisions can be quite different and difficult for individual mental models to evaluate. Although the human brain is capable of providing part of the answer, this becomes more difficult when multiple factors interact, and linear extrapolation of historic patterns is inadequate. This is certainly true for complex social-environmental systems that are rapidly developing, with economic activities competing for resources such as space, water, energy and skilled labour. While causal loops and narrative scenarios, as developed in the first phase of the project, are useful for conceptual analysis of problems and solutions, the models have an added value for sensitivity testing of different policy actions and act as a laboratory for policy testing under different scenarios. The strengths of SD modelling, compared to other types of models, are the holistic perspective, evaluation of system feedback, consideration for systemic limits, tipping points and non-linearities, the graphical interface of models allowing interactive design and high computing speeds. Foremost, SD models should be applied to complex social-environmental problems that can be explained and addressed by understanding from the underlying feedback dynamics and not replace other types of models (cost-benefit analysis, GIS analysis, hydrological modelling, ...) in case these are more appropriate. Nevertheless, SD models can be useful as an integrative platform for thematic models (Figure 1).

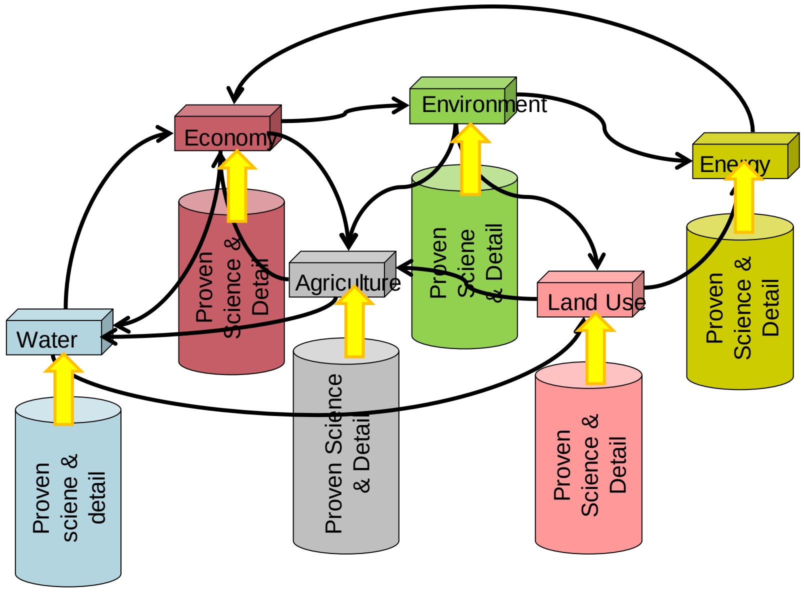

Figure 1 Thematic integration using a system dynamics framework (De Kok et al., 2017).

Starting from the mental models developed with the stakeholders in the sector workshops (Tiller et al., 2019) and multi-actor workshops (Tiller et. al, 2021), the project consortium developed a large number of sector specific and integrated stock-flow models. The models, design trajectory and applications have been described in detail in deliverables D13 (Viaene et al., 2020) and D14 (Viaene et al., 2021). The design, technical implementation and calibration of SD models can be challenging, particularly when stakeholder engagement results in overly complex or ill-balanced causal loop diagrams or modellers are less familiar with SD modelling. In this respect a generic library of reusable model components (De Kok et al., 2015) and model archetypes can be very useful to facilitate model maintenance, adjustment and the exchange of model constructs between different modelling teams. This will free resources for other relevant activities such as stakeholder engagement and model applications, rather than model engineering. One of the reasons why more experienced and skilled SD modellers develop their models more rapidly and efficiently is that they are used to design and adjust their models based on generic archetypes (feedback structures) linked to the problems examined and a step-wise design process. Low-level examples of generic archetypes and feedback structures generating different dynamic patterns were already presented in Table 1 of deliverable D12 (De Kok et al., 2020). These examples are useful for explaining the principles of SD modelling and the importance of feedback structures but are of less practical use for advanced modellers and complex modelling exercises with a specific focus. On the other hand, complete SD models are usually too context specific and lack genericity, making them less useful for reuse in other applications without detailed understanding of the model and underlying processes.

A basic tutorial example of a stock-flow model for tourism development was used during the project kick-off meeting to introduce the principles and added value of SD modelling (Figure 2).

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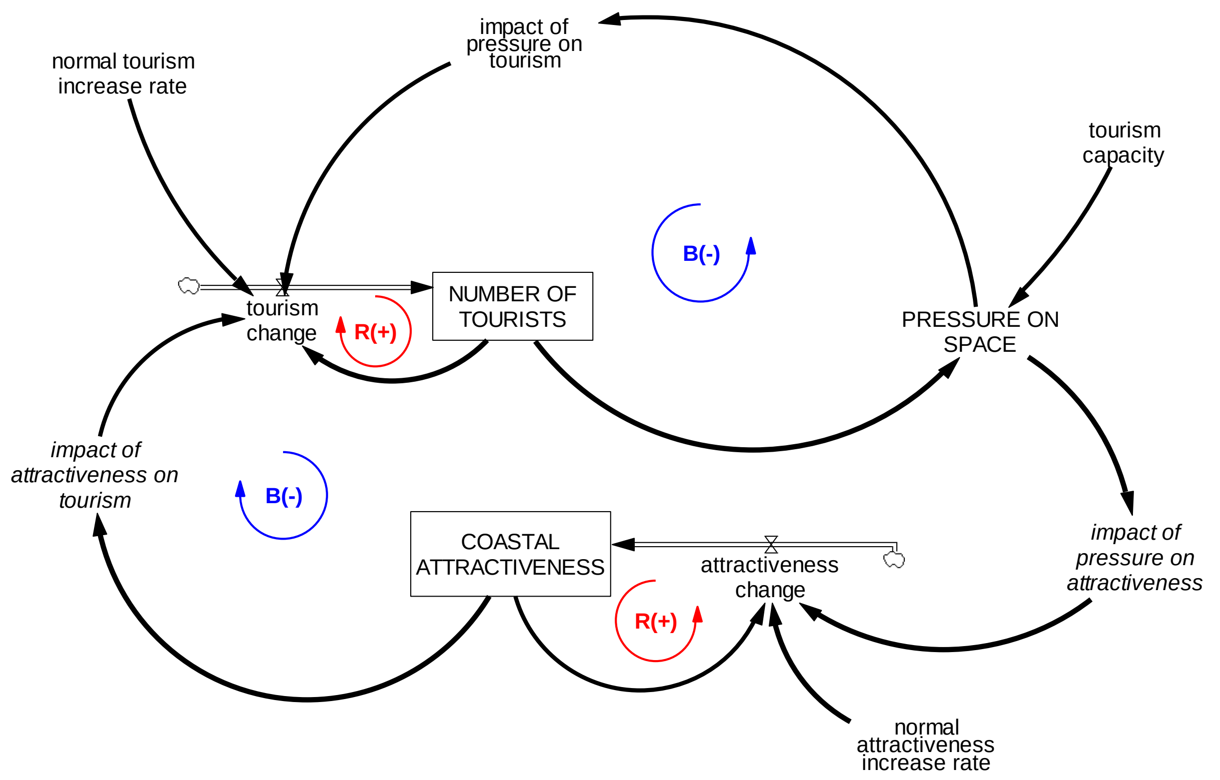

Figure 2 Tutorial example of a stock-flow model for tourism development used during the project kickoff meeting (June 2018) with reinforcing (R) and balancing (B) feedback loops indicated.

Though basic in design, the model can generate overshoot-and-collapse behavior, with a tipping point reached when the volume of tourism surpasses a critical threshold, resulting in decline. This feedback structure is a good starting point for introducing tourism or other new economic activities in a model, making it useful for inclusion in a generic model library. Further development, quality control and technical support should be the basis for gradual expansion of the library with new and improved tools and the creation of a community of users.

To maximize the potential for reuse, generic model constructs should aim to meet the following criteria:

a) The level of detail and model granularity should be appropriate with a proper balance between genericity and relevance for the problem context. Low-level, mathematical constructs and complex, overly context-specific model constructs are less useful for incorporation in a generic toolbox;
b) Each construct should ideally be embedded in a self-explaining example application including data to run model with errors;
c) Proper documentation should complement the tools to clarify model assumptions, the interpretation of dynamics and potential applications;

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d) The tools should be complementary, avoiding duplication of model constructs and strengthening the usefulness of the library.

The following interrelated model design criteria are relevant for generic model constructs as they can affect the potential for reuse and need to be clarified:

- **Scope**: refers to the number and breadth of processes, sectors and/or themes captured within the boundaries of the model. A single-theme model focusing on, for example, the decommissioning of wind turbines is generally more narrow in scope than models integrating multiple themes. Models that are wider in scope potentially offer more generic constructs, but the effort needed to identify and further develop them will be higher. Furthermore, the model scope may be context specific – reducing the potential for reuse in other models or applications.
- **Complexity**: refers to the way the models is structured (for example there may be interacting modules or the model may be designed in hierachical levels) and the number of interactions between variables. The higher the number of variables and interactions, the more difficult it is to retrieve reusable components from the model;
- The level of detail or **granularity** of a model (De Kok et al., 2015; deliverable D12) refers to the way it is composed of individual parts or variables. The complexity of SD models should be in the feedback structure and interactions between variables rather than the total number of variables. The reason is that this feedback structure determines the dynamics of the model and hence the way the model responds to policy and business decisions. Excessive model granularity is to be avoided, certainly in the earlier phase of the modelling process. Instead, the focus should be on understanding problems from the correct feedback structure. Ill-designed models often show imbalances in the granularity or a granularity that is inappropriate for the intended purpose of the model (lack of detail or excessive detail). A high degree of model granularity increases the complexity and effort needed to identify and retrieve reusable model constructs and system archetypes, even if these exist;
- **Modularity and encapsulation** (De Kok et al., 2015): a model may be designed around well-defined and encapsulated modules with a limited number of connectors. In principle, these modules should be exportable with a high potential of reuse, provided modellers can rely on the functionalities of the module without accessing or adapting the internal structure of the module;
- Finally, the **interoperability** of model constructs affects their potential for reuse in a generic toolbox. This means the model constructs should be well encapsulated and designed with limited but appropriate connectors and complementary functionalities. Particularly, the latter design criterion is more relevant for a mature toolbox consisting of sufficient different components. However, SD modellers should anticipate this requirement when working towards a generic toolbox and carefully consider the scope, number and connectivity of their model constructs. The larger the number of connectors, the lower the potential for reuse.

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In 2015, El Sawah, Lucas and Ryan[1] provided an overview of the use of generic and reusable structures in SD modelling. They distinguished:

1) Canonical Situation Models: fully tested and calibrated models encapsulating the essential structure explaining the dynamics behind a problem and adaptable by adjusting parameters;
2) Microstructures: abstract, elementary structures covering a broad range of system dynamics models;
3) Counter-intuitive archetypes: conceptual models (causal loop diagrams) explaining the dynamics behind counter-intuitive impacts of a policy;
4) Molecules: standard model structures, organized in a hierarchical system;
5) SD Meta Models: high-level architecture of domain objects and interactions, requiring high-level programming;
6) SD Object Oriented Components: software including model equations and diagrams.

In the context of COASTAL, the generic structures for the toolbox should have some degree of context-specificness (related to land-sea interactions and/or regional development), surpass abstract microstructures and molecules, and thereby facilitate the modelling process as much as possible. This points to a level somewhere between that of the canonical situation models and counter-intuitive archetypes such as the example of Figure 2.

The typical strengths of the current COASTAL models (see deliverable D14) can be summarized as follows:

a) The modelled priorities, key stock variables, scenario drivers and policy indicators were identified **based on direct engagements** with a broad selection of over 500 stakeholders, in interactive, holistic settings covering a wide range of themes across the land-sea interface (agriculture, water management, renewable energy, tourism, spatial planning, ….);
b) All models were systematically **screened** in terms of design, completeness and usefulness (see Annex 2 of deliverable D14) and passed tests to verify the **consistency of equations and dimensions**;
c) Model **granularity has been minimized** to the extent possible, i.e. the models are well-balanced in terms of the level of detail throughout the model. This increases the model transparency;
d) All models were developed in the VenSim® **common software platform** for SD modelling, enabling interoperability of models and exchange of reusable model constructs. Runtime versions can be shared with third parties or stakeholders for further distribution;
e) A **complete and harmonized documentation** of the model equations, variables and parameters has been generated automatically, and can be found in Annex 6 of deliverable D14;

[1] https://proceedings.systemdynamics.org/2015/proceed/papers/P1078.pdf

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f) All models were exported to ISEE Player to support the documentation, making them available in the Stella modelling platform;
g) The more complex models have been organised around different modules in VenSim ’views’, connected through clone copies of key variables.

The MAL models were not designed with the purpose of contributing to a generic library of reusable model components, and the majority of the land-sea models of the MALs are wide in problem scope, complexity and granularity with limited effort spent on structuring the models around interacting modules. Nevertheless, generic feedback structures and reusable model can be observed in or retrieved from the models relatively easily. Contributions to a generic toolbox and the KEP may consist of:

a) A set of polished, validated, well documented and complementary stock-flow models with a problem scope relevant for or related to land-sea interactions and land-sea synergy;
b) Tutorial model simulations demonstrating how stock-flow modelling can support policy analyses of social-environmental systems with a focus on land-sea interactions;
c) Generic, reusable model constructs that can serve as components in a generic model library.

This deliverable focuses on the third topic as the first two where already elaborated in deliverables D13 and D14. We provide an overview of the generic model constructs that can be derived from the stock-flow models that were developed by the Multi-Actor Labs (MALs) or in support of the modelling process. Obviously, well designed and documented model structures are of greater value, surpassing application to land-sea systems.

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2. GENERIC TOOLS AND GUIDELINES - WP4

The VenSim® software comes with a large number of functions in a library, example applications and a library of so-called VenSim Molecules[2] for designing models. Not all functions are available for the cheaper and cost-free licenses, and these generally concern technical and mathematical functionalities rather than the specific issues encountered by the modellers of the MALs. Therefore, a wide range of tools, model constructs and tutorial examples were developed in WP4 to assist the MALs with the modelling of their land-sea interactions and address technical issues related to modelling with the VenSim® software. For example, model constructs with examples were developed to demonstrate how monthly seasonality could be introduced in a model running with a time base of years, how data can be imported in models, how to work with non-linear response functions or how to derive averages of extreme values for indicators in the models. Validated, documented and running examples were considered more useful than referring to the literature and VenSim user manuals and were easily distributed through the project website and, later, the sharepoint. The topics addressed with these tools were guided by questions raised by the partners. We present a selection of the tools considered useful for a generic library and distributed to the partners as examples or to address technical issues. Often alternative options are available to solve a problem and a choice should be made to use the most appropriate solution.

2.1. Introducing seasonality

A stock-flow model may be designed to run, for example, with a yearly time base. However, it may be necessary to downscale some variables and add more temporal detail. For example, it can be useful to obtain monthly temperature values from a scenario with yearly averages. It may be less desirable to redesign the complete model to a monthly time step. A practical solution is to introduce an index for the month (value 1-12) in the model and impose the seasonal pattern in the model using a look-up table (Figure 3).

[2] https://vensim.com/modeling-with-molecules-2-02/

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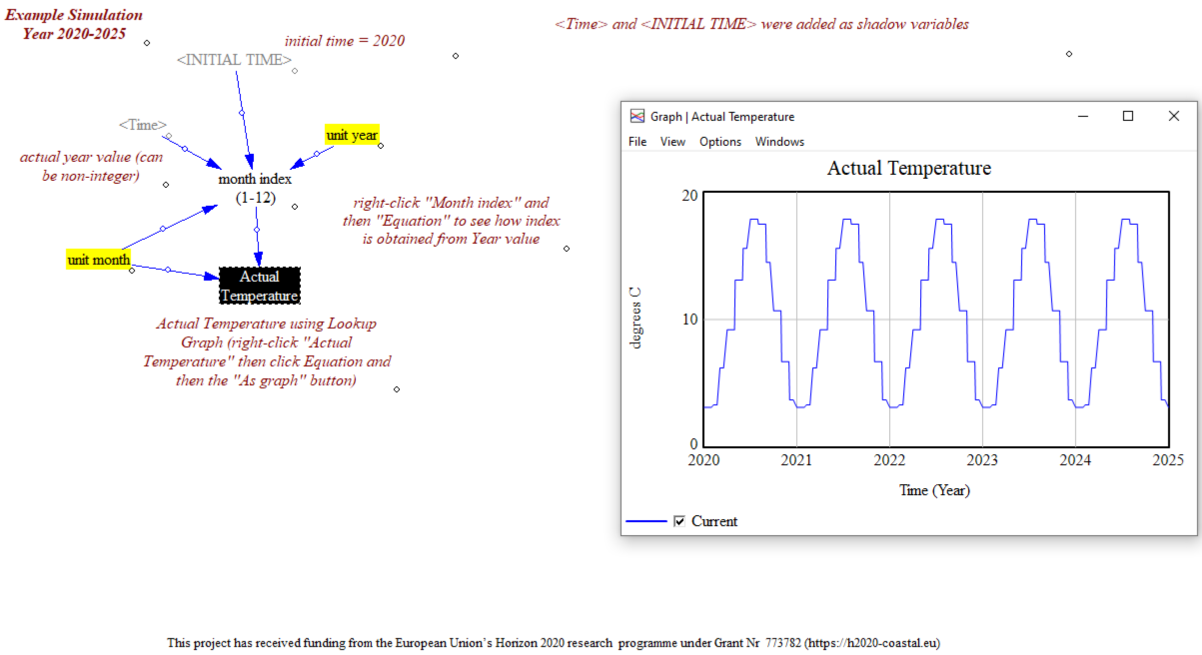

Figure 3 Introducing seasonality in a model using a look-up table.

Alternatively, one can read the pattern from a data file using the standard VenSim function GET XLS LOOKUPS. The ready-to-use examples with documentation were considered very useful by the partners and could quickly be exported to the models.

2.2. Importing external data

Model parameters, initial values of variables and time series for drivers of change can all be imported from external files (usually spreadsheet). Figure 4 shows how the function GET XLS CONSTANTS can be used to import a constant into a model.

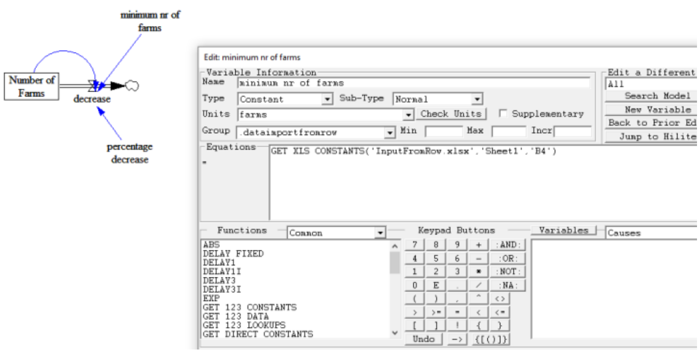

Figure 4 Tutorial example model demonstrating how to import a model parameter into the model.

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2.3. Scenario coupling tool

The narrative scenarios developed in WP5 will be integrated with the stock-flow models to support the (re)design of the business and policy road maps. A tool was developed in WP4 to allow the MALs to import scenarios into the model. Each scenario can be defined by the setting the range and shape of the trend (linear, exponential, etc.) for the scenario (**Error! Reference source not found.**).

	Var1-SSP1	Var1-SSP2	Var1-SSP4	Var1-SSP5	Var2-SSP1	Var2-SSP2	Var2-SSP4	Var2-SSP
select scenario type	1 = linear	3 = exponential slow	2 = exponential acce	4 = S-shaped	3 = exponential slowing d	1 = linear	5 = parabolic	2 = exponential acce
initial value	50	50	50	50	20	20	20	
final value	70	70	70	70	88	88	88	

	Var1-SSP1	Var1-SSP2	Var1-SSP4	Var1-SSP5	Var2-SSP1	Var2-SSP2	Var2-SSP4	Var2-SSP
2020	50,00	50,00	50,00	50,13	20,00	20,00	20,00	
2021	50,67	52,00	50,11	50,19	26,81	22,27	27,35	
2022	51,33						34,27	
2023	52,00						40,78	
2024	52,67						46,86	
2025	53,33						52,53	
2026	54,00						57,78	
2027	54,67						62,60	
2028	55,33						67,01	
2029	56,00						71,00	
2030	56,67						74,57	
2031	57,33						77,72	
2032	58,00						80,44	
2033	58,67						82,75	
2034	59,33						84,64	
2035	60,00						86,11	
2036	60,67						87,16	
2037	61,33						87,79	
2038	62,00						88,00	
2039	62,67						87,79	
2040	63,33						87,16	

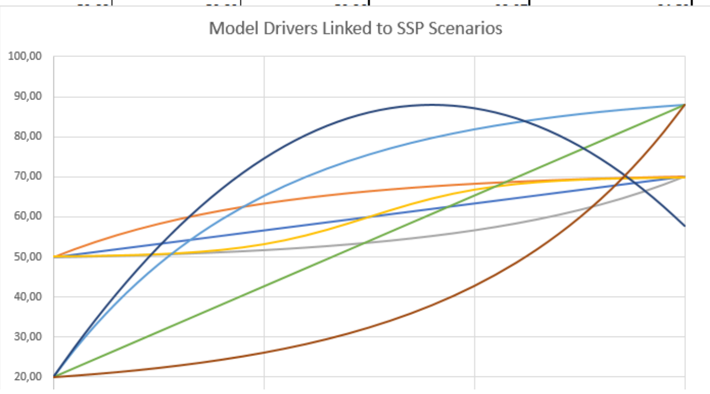

Figure 5 Setting scenarios.

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An example application with a slider to switch between scenarios was added to demonstrate the use of the tool (**Error! Reference source not found.**).

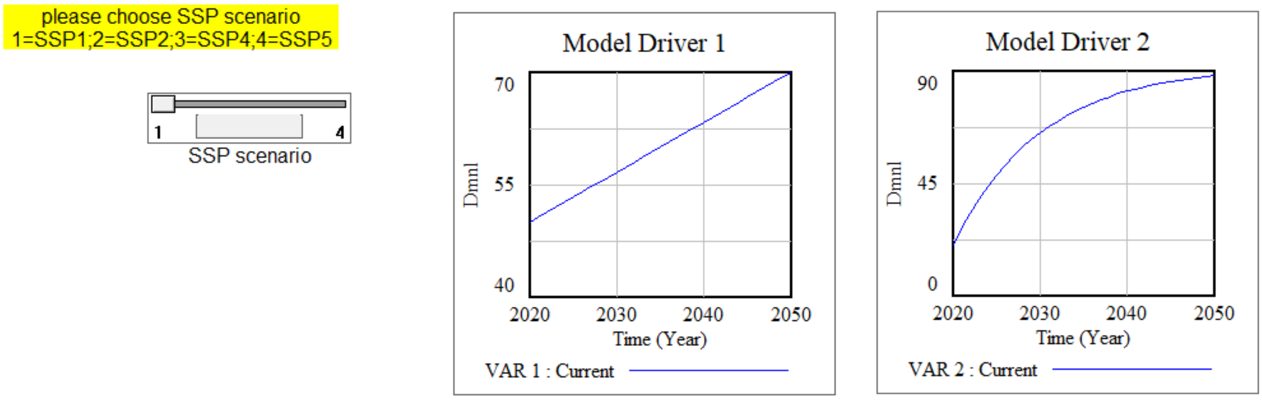

Figure 6 Scenario slider for use in VenSim models

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2.4. Introducing human behavior and soft variables in models

The possibility of introducing variables and feedback structures related to human behavior in models is one of the strengths of System Dynamics and an important asset for policy analysis. So-called ’soft’ variables are human or environmental factors that are difficult to measure or quantify. Examples are public awareness, landscape quality and environmental pressure. Nevertheless, these factors can have an important role in closing feedback loops and the policy implications generated with a model. The recommendation is therefore to include these factors in the models (Sterman, 2001). The MALs were assisted with examples on how to include such ‘soft’ variables. Counterintuitive responses of systems are often due to societal or organisational aspects related to so-called ’soft’ variables, such as perception and awareness. In order to use these variables in models, they should be at least measurable on an ordinal scale, and are usually introduced as a dimensionless index (range 0-100). The recommendation is to include these variables, even if they are difficult to measure directly, rather than leave them out (Sterman, 2001). A more complex model for a groundwater model was developed and demonstrated step-by-step to illustrate the importance of closing a feedback loop through such a soft variable, in this case, the awareness of water shortage.

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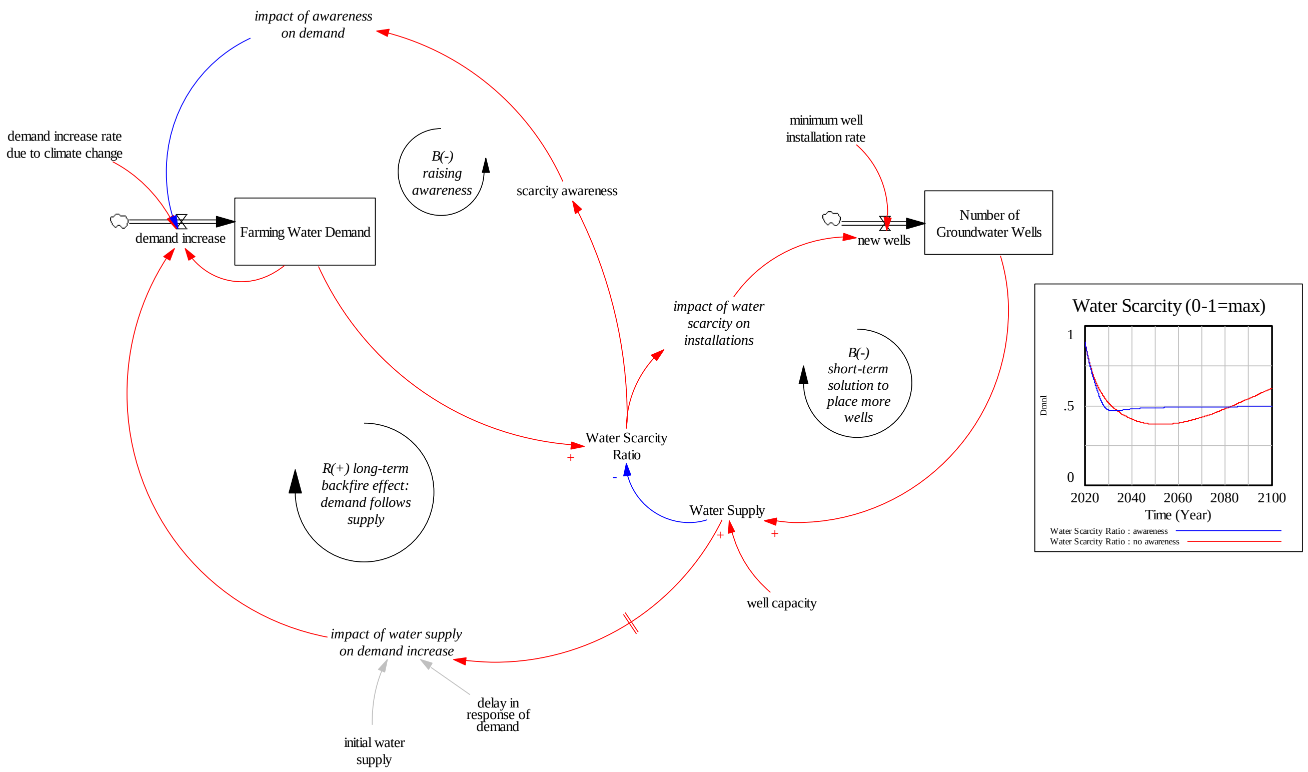

Figure 7 Impact of introducing awareness on long-term water scarcity.

2.5. Modelling transition processes

In a more complex and context-specific example, transition processes are relevant for all MALs and can easily be modelled using generic structures. For example, the intensification of fish farming and transition to ecofarming for the Romanian MAL were modelled with a similar model construct, although with different variable labels and parameter settings (Figure 8).

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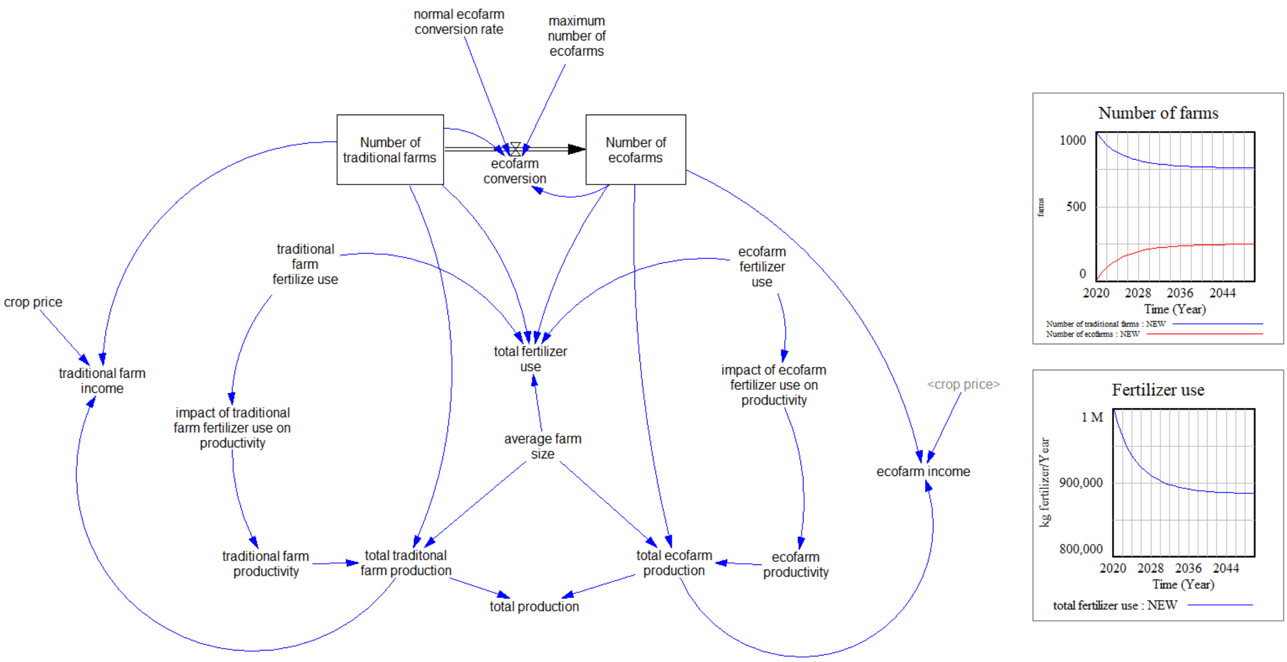

Figure 8 Reusable model structure for transition of an economic sector from traditional to more sustainable production.

2.6. Generic table functions/graphical functions

Use of table functions: in SD modelling table functions are useful for quantifying the interactions of variables which are difficult to capture in mathematical equations, for example, the impact of awareness on water use. For this, SD software provides the option of using graphical table or 'look-up functions', preferably using normalized (dimensionless) input and output. Examples were used to clarify the use of these functions, generally appearing in the models as "impact of variable X on variable Y". The range of the functions was to be set. For the shape of the relationship in the graph, the MALs were provided examples such as the S-shaped curve and growth/decline saturating functions as tables in Excel.

2.7. Automatic estimates of growth rates

Growth rates are parameters affecting the model dynamics. These turned out to be difficult to define or calibrate based on the literature and available data. For example, a transition from traditional to eco farming can be expected to occur at a certain rate of growth, while slowing down when a maximum (saturation) level is attained. Both the MALs and stakeholders were challenged to reflect on the existence and role of these growth rates and saturation levels. A technical solution using the logistic growth model was developed to

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derive the growth rates in an indirect way from a critical threshold level, the initial condition for the variable, the saturation level and the time to reach the threshold (Figure 9). Defining a critical level as fraction of a saturation level and the time to reach this level is generally easier than the mathematical concept of a growth rate.

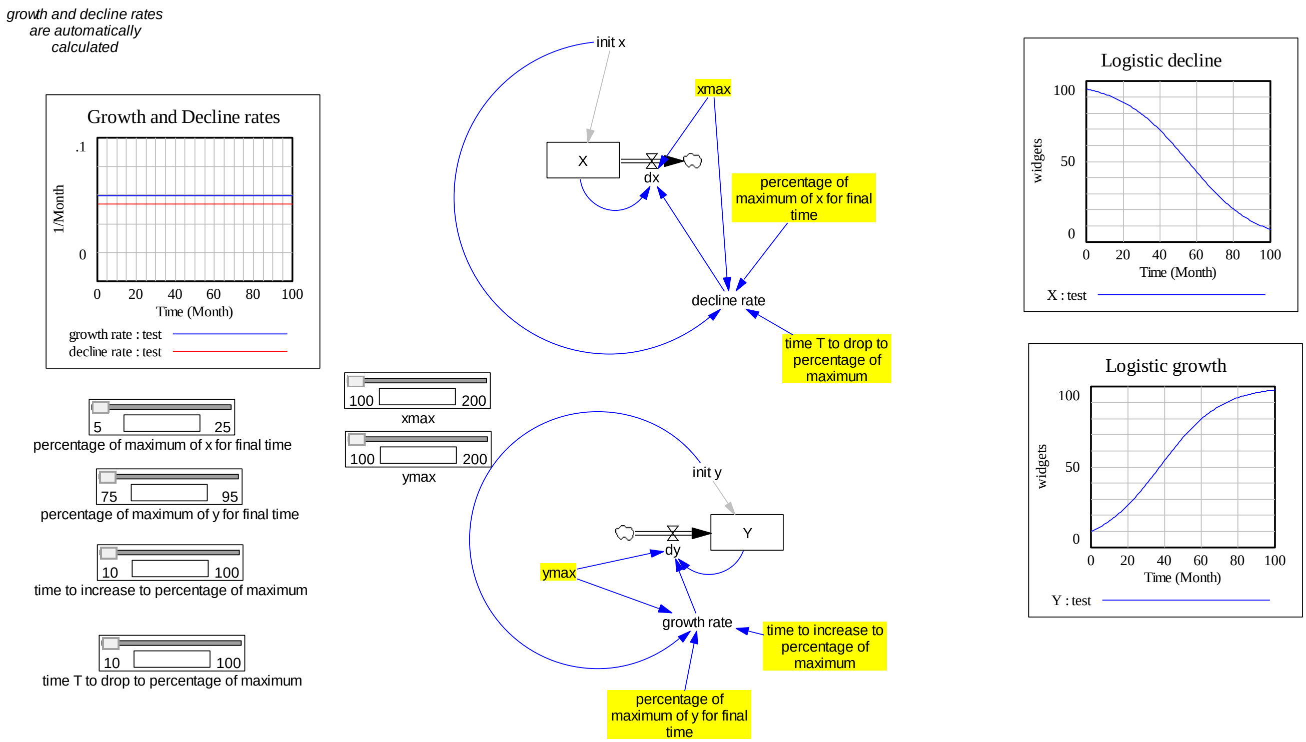

Figure 9 Automatic calculation of growth and decline rates from target values and time to reach these.

Logistic growth is a common phenomenon in social-environmental systems and generated by the corresponding system archetype described in deliverable D12 (Figure 10). The difference equation for logistic growth of a variable X(t) is:

$$dX = g\,X\left(1 - \frac{X}{X_{max}}\right) \qquad (1)$$

where g is the growth rate and X_{max} the maximum (saturation) level.

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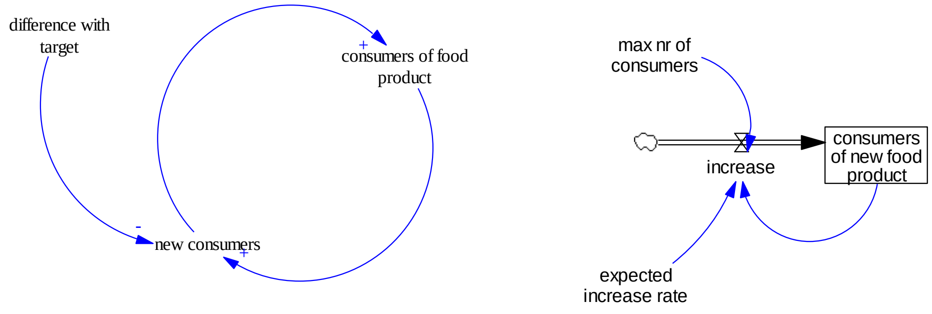

Figure 10: Examples of a causal loop and stock-flow diagram generating logistic growth (see deliverable D12)

Equation (1) can be solved analytically (Sterman, 2001) with the solution:

$$X(t) = \frac{X_{max}}{1+\left(\frac{X_{max}}{X_0}-1\right)e^{-gt}} \qquad (2)$$

where x_0 is the initial value of the variable. The growth rate *g* can be estimated from historic data (model calibration) or obtained based on expert estimate. Interactions with experts and stakeholders proved that the concept of growth rates is difficult to communicate and discuss. The logistic growth model can be explained more easily and the growth rate determined indirectly by asking for: (1) a critical threshold level defined as a fraction α of the saturation level X_{max} and (2) the time *T* expected for the variable to reach this threshold level. This information can then be used to derive the growth rate by solving for $X(T) = \alpha X_{max}$. This gives (Sterman, 2001):

$$g = \frac{1}{T}\log\left(\left(\frac{\alpha}{1-\alpha}\right) \times \left(\frac{X_{max}-X_0}{X_0}\right)\right)$$

This approach was used to calculate the transition growth rate for ecofarming and the tourism development growth rate for the Romanian MAL (see D14).

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Likewise, the decline of a stock variable from the maximum of it's range Xmax to a fraction α of the maximum

2.8. Deriving averages and extremes for policy indicators

Although the VenSim PLE and PLP licenses used in COASTAL come with a large set of tools and functionalities, not all VenSim functions are available. There was a need to improve the graphics of the model and time graphs used in the policy dashboard by deriving mean and extreme values shown with an adjustable time interval (Figure 11). The concept was designed and tested with the Oudland polder model but is reusable for any type of VenSim model.

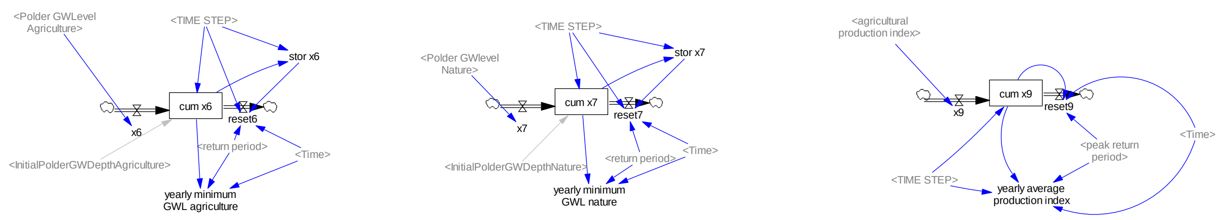

Figure 11 Reusable model constructs in VenSim to derive mean, minimum and maximum values of indicators with an adjustable time interval.

These tools can be used to remove undesirable fluctuations from model indicators with a high degree of periodicity and/or fluctuation, making the mid- and long-term dynamics easier to read and interpret.

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2.9. Impact of spatial pressure on coastal real estate market

All along the Belgian coast one can find appartment blocks with seafront views. Investment in these apartments is a booming and profitable business. The downside is that this development affects the visual quality of the coastal towns. This does not seem to affect appartment pricing today, but it could become relevant in the future, particularly when regulations become more strict. A sample model was developed to describe the interaction between demand and supply of apartments and the price setting.

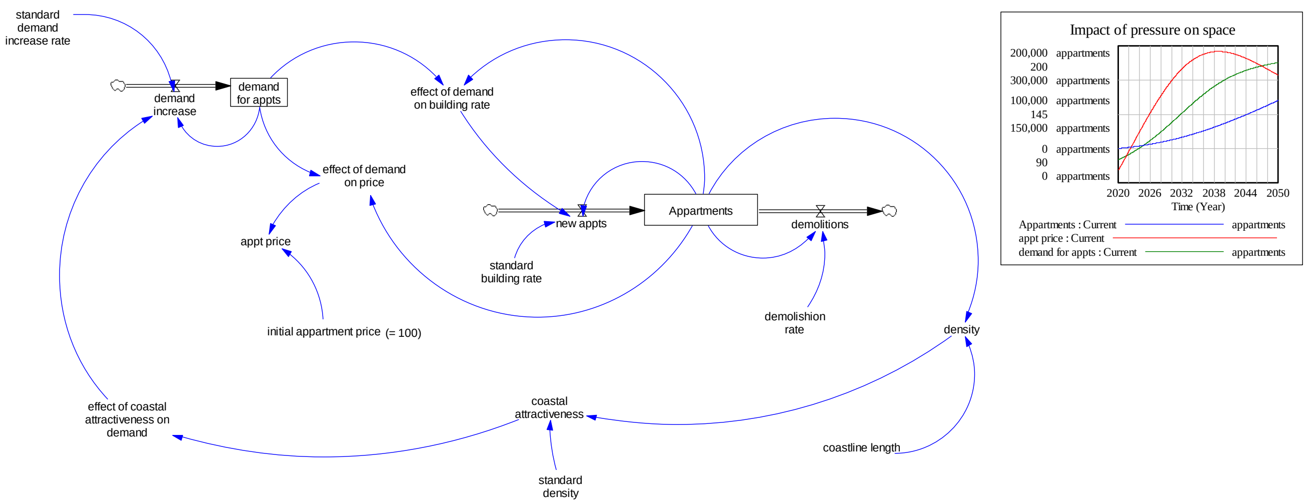

Figure 12 Impact of coastal real estate development on visual attractiveness and pricing of appartments.

The underlying mechanisms are similar to that of the tourism model (Figure 2) – though with a more specific problem context.

2.10. Fish farming

Fish farming is a relevant sector for several of the MALs. A generic structure was developed as an example for the development of a new business, addressing both economic and environmental aspects, including the use of space.

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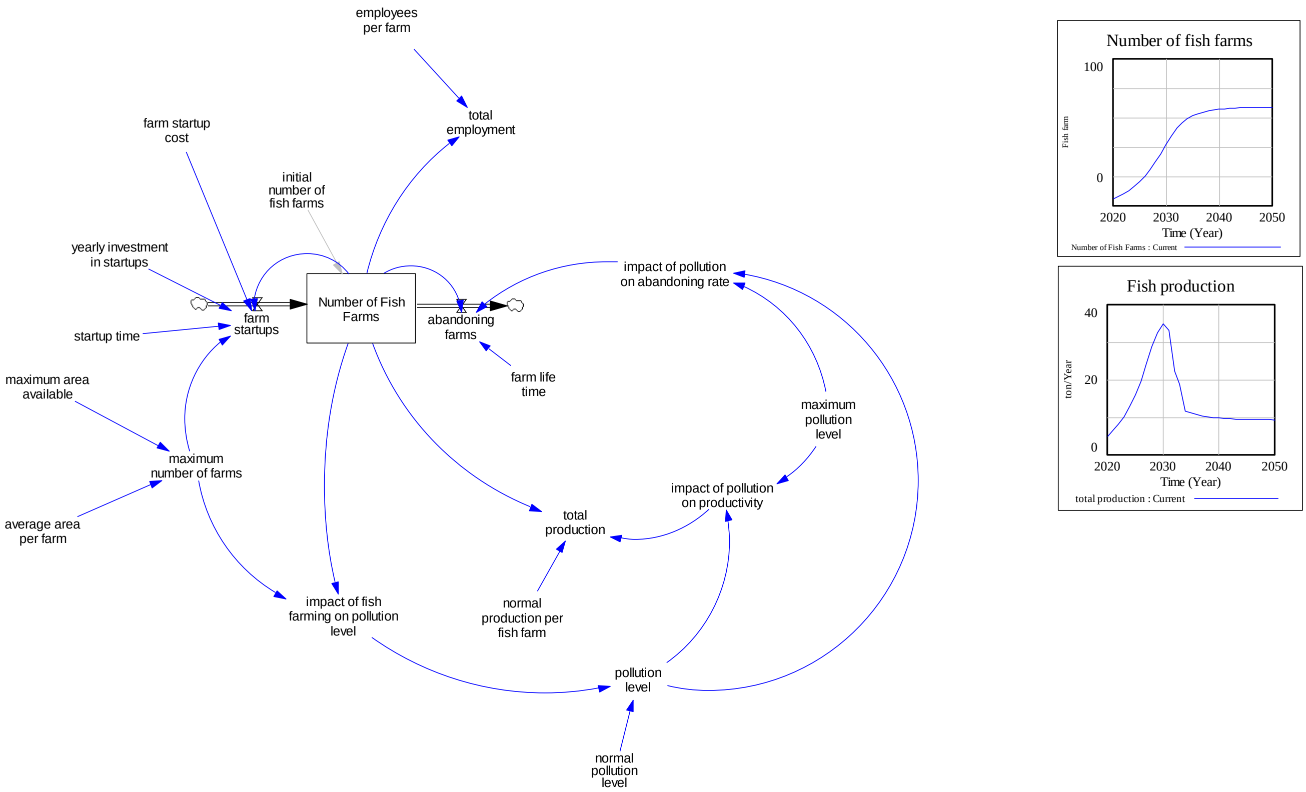

Figure 13 Generic structure for starting up a new sector, with fish farming as an example.

The model produces a tipping point in the production of fish due to an excessive development of the number of farms, leading to pollution, which in turn affects the farm productivity. Field samples, statistics and ecosystem models should be used to tune the parameter settings and response functions used to close the feedback loops.

2.11. Modelling guidelines

Modelling guidelines are even more important than generic tools to support the modelling process and an integrated part of the SD modelling toolbox. A good overview is found in Sterman (2001). Several measures were taken to maximize the efficiency and harmonization of the modelling (deliverable D14):

- Instead of modelling the complete system in a top-down manner, covering all interactions indicated in the Causal Loop Diagrams (see deliverable D4), the MALs were encouraged to identify the priorities for their modelling and first develop sub models that were only integrated once these were running;
- The MAL teams were assisted through weekly exchanges with the WP coordinator to discuss the progress of the modelling, problems and develop solutions. Initially, these meetings were organised with all teams. Later, follow up was only for those teams that needed support ;
- Additional tutorials and guidelines were distributed to direct the modelling at a strategic level;
- Technical support for model documentation and online exchange of models through the project website and Sharepoint were provided. The exchange of models was facilitated by the use of VenSim® as a common modelling platform;
- Modelling workshops were organised, during the General Assembly meeting in Methoni and in connection with the first Review meeting in Brussels, as these were occasions where everyone was already present.
- A structured template for deliverables including examples was provided.

The general modelling strategy communicated to the partners was based on three principles:

1. identify the key stock variables based on the causal loop diagrams;
2. follow a step-by-step design process with gradual increase of complexity of the models;
3. focus on the quantification by measurable variables, use of non-linear response functions, system limiting factors and correct units of measurement.

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3. GENERIC TOOLS - MALS

3.1. MAL01 – Belgian Coastal Zone

Following exchanges with the stakeholders, it was decided to prioritize the modelling for this MAL around two themes related to rural development and blue growth (Figure 14):

- Climate resilience of the Oudland Polder: Impact of climate change and water management on polder land used primarily for farming and nature;
- Decommissioning of offshore wind parks: offshore energy production, maintenance and decommissioning coupled to employment, port development and onshore infrastructure;

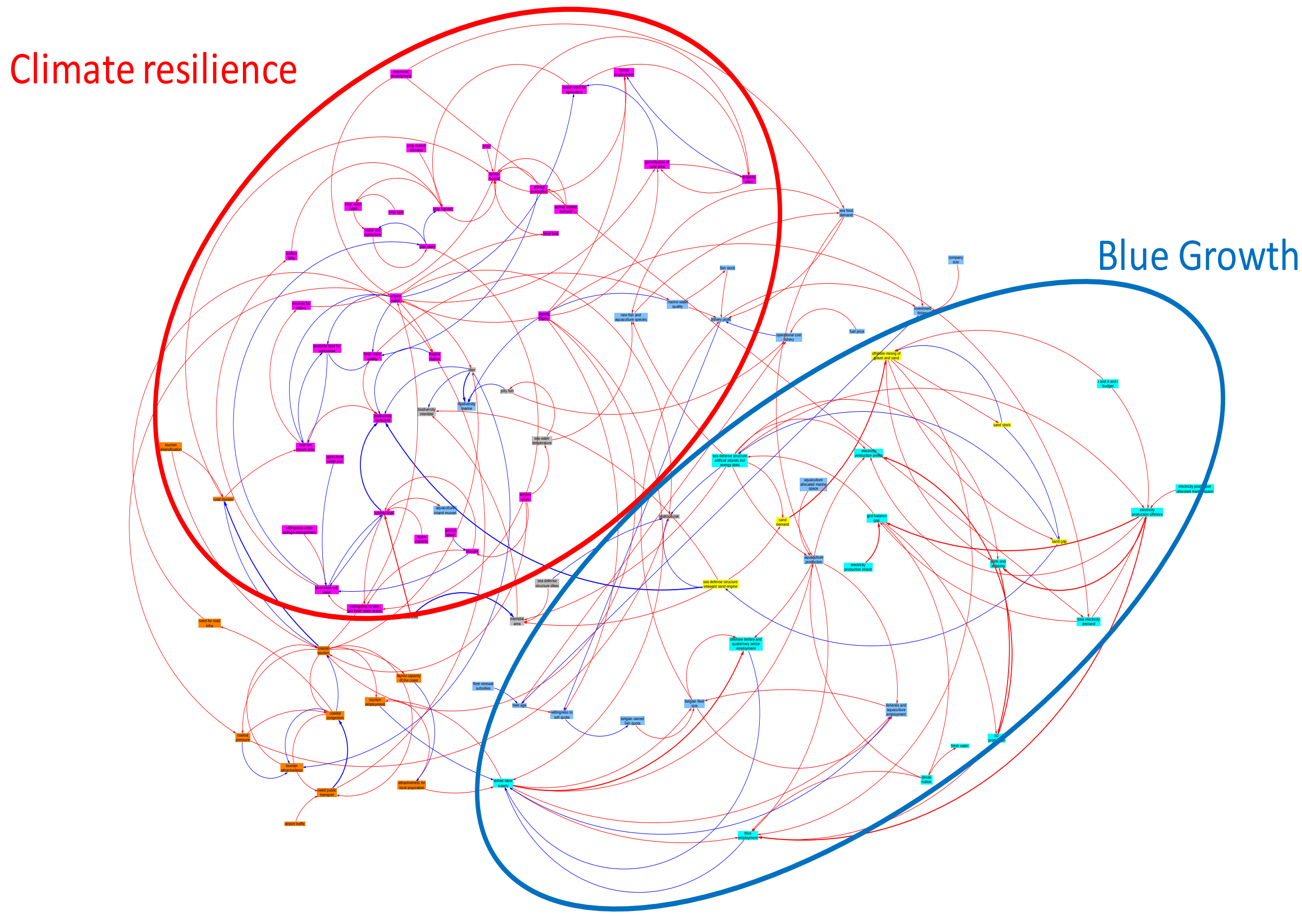

Figure 14: Positioning of the disjunct themes of climate resilience and blue growth within the CLD for the total land-sea system.

It was not considered meaningful to integrate these two themes in a single land-sea system model as cross-thematic interactions were not identified earlier in the project. Instead, it was deemed more useful to analyse the land-sea interactions for the two themes individually and focus the modelling of the themes on the economic and environmental variables relevant for rural development and blue growth. The following chapters are devoted to providing a more detailed account on how this was done.

For the **Oudland polder model** the stock-flow model structure links land use planning with water management and gentrification in agriculture (Figure 15). The complexity of the model is in the equations and data rather than the feedback structure. The water management is different for areas intended for agriculture and nature. One of the questions raised by stakeholders was how introducing separate compartments for the land occupied by agriculture and by nature could affect the water balance for these areas. The water component of the stock flow model furthermore allows investigating the effect of changes in the different water sources and sinks including natural ones such as precipitation and evapotranspiration which will change with climate change but also water reuse from waste water treatment plants or rainwater collected from paved areas and the buffering of water in creek ridges. The latter all being forms of possibilities for human intervention in the polder water balance. A somewhat different topic covered by the stock flow model is the gentrification of farms in the polder region. While this is, as it is modelled now, mostly an autonomous process in the model, some feedback was introduced to account for effect of land use changes on gentrification. The gentrification model is also affected by the water management by considering the effect of water management on suitability for agriculture / nature. Land-sea interactions are included through the impact of sea level rise on water discharge for the polder. This is not an immediate concern for this region, but the problem was raised several times during the sector workshops and implies that the installation of pumps to remove water will be necessary in the future.

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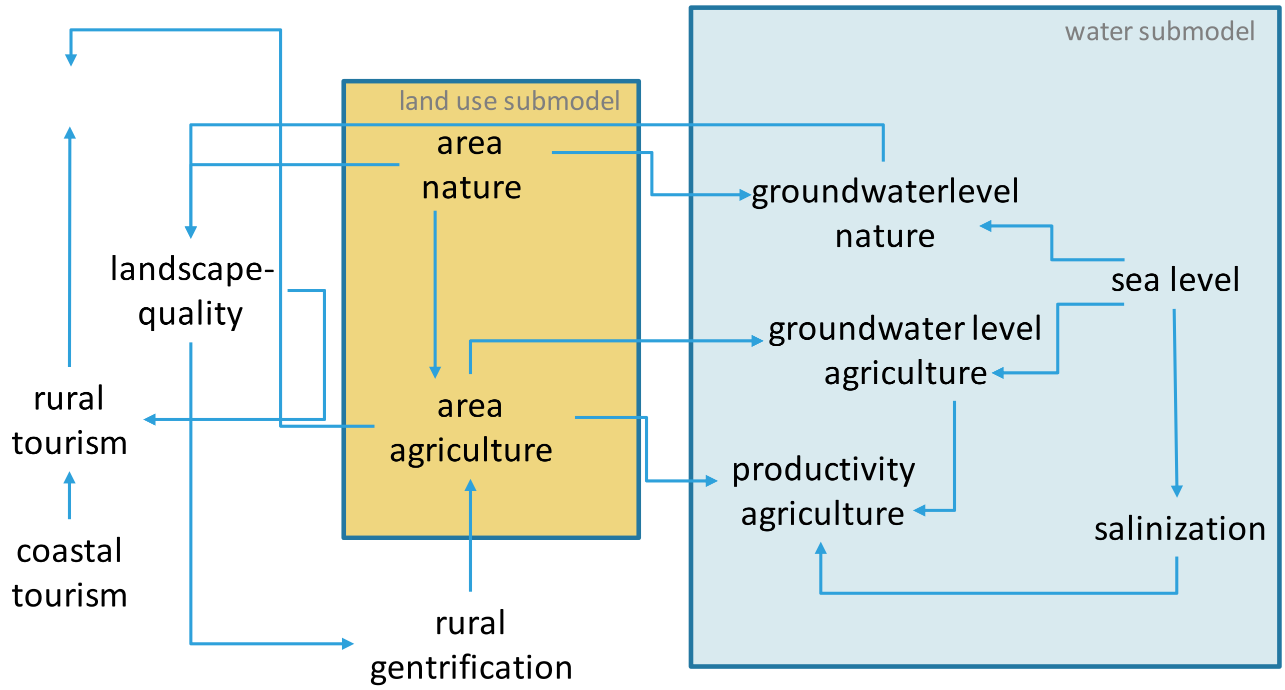

Figure 15 General feedback structure for the Oudland polder model.

For the **port and energy model**, now focusing on the decommissioning of offshore wind turbines, the systemic analysis covers the logistics, economic and energy aspects of offshore wind farming (Figure 16). With the decision to focus the model further around the **decommissioning rate** (the long-term pattern of the yearly number of decommissioned turbine), it was necessary to reconsider the definition of stock and flow variables and use the age-cohort system and age-based stocks to build up the model. At a general level, this is not a complex model both in terms of the feedback structure and equations used. Some feedback is present in the age-cohort chains. In line with the reality of marine spatial planning in the Belgian coastal zone, the model is strongly exogenously driven by planning scenarios for installation of the turbines and technological factors, such as the turbine capacity and maintenance costs. Intrinsically, the final model is a graphically designed accounting model. The holistic value of the model could be increased by including the impacts of systemic limitations, for example a lack of skilled labour or port space could limit the capacity for decommissioning the wind turbines. Some tests were run to examine the potential usefulness, but this was considered to be of academic and educational value rather than practical value for the priorities indicated by the actor partners. Therefore, the priority is given to improving the data used by the model and discussing the usefulness of the model simulations for long-term planning with selected stakeholders. This will be done in conjunction with the EU-funded project DecomTools[3], which focuses more on the engineering and technological aspects, and

[3] https://northsearegion.eu/decomtools/

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short-term planning of decommissioning. In the future, the model could be elaborated in terms of material reuse and the impacts/demands on port infrastructure.

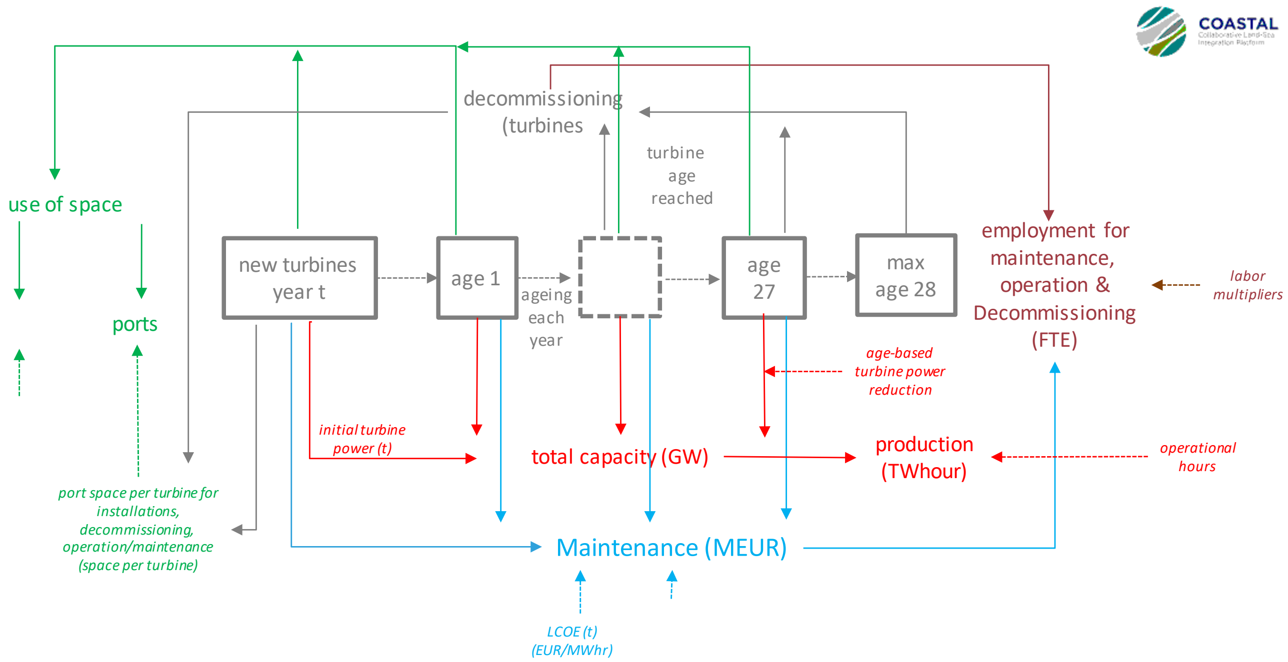

Figure 16 Port and Energy model focusing on the logistics and economic impacts of decommissioning offshore wind turbines (see deliverable D14).

The port and energy model has been fitted with a policy dashboard showing a broad selection of key policy indicators related to the actual size of the wind park, the decommissioning and installation of turbines, the energy production capacity, maintenance costs, use of space and employment (**Error! Reference source not found.**). The model can be used for long-term planning related to the logistic, infrastructure and economic aspects of installing and decommissioning offshore wind turbines. The generic model core based on age-cohorts for turbines and modular design of the model using separating scenarios, policy indicators, engineering and economic aspects of the model, and input data is flexible and can easily be adapted or updated.

Typical interventions and policy impacts that can be examined with the model include:

- New (spatial) planning scenarios for offshore wind parks;
- Different technological scenarios (power, size and life time of the turbines, maintenance costs);
- The implications on direct and indirect employment, both onshore and offshore;
- Examining the role of specific parameters, such as the time required for installing and decommissioning the turbines, the yearly operational hours and the power loss rate.

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The port and energy model is relevant for mid- and long-term strategic planning of offshore wind energy production in the Belgian North Sea and other EU territories, the contribution to achieving carbon neutrality by 2050, and the port infrastructure planning. With respect to the EU regulatory frameworks and directives, the model is of relevance for the EU Green Deal, EU-MSFD, and the EU Blue Growth Strategy.

The main model construct with potential for reuse is a feedback structure for **rural gentrification** which takes into account the interaction between changes in the function of farms, the profitability and farm price (Figure 17).

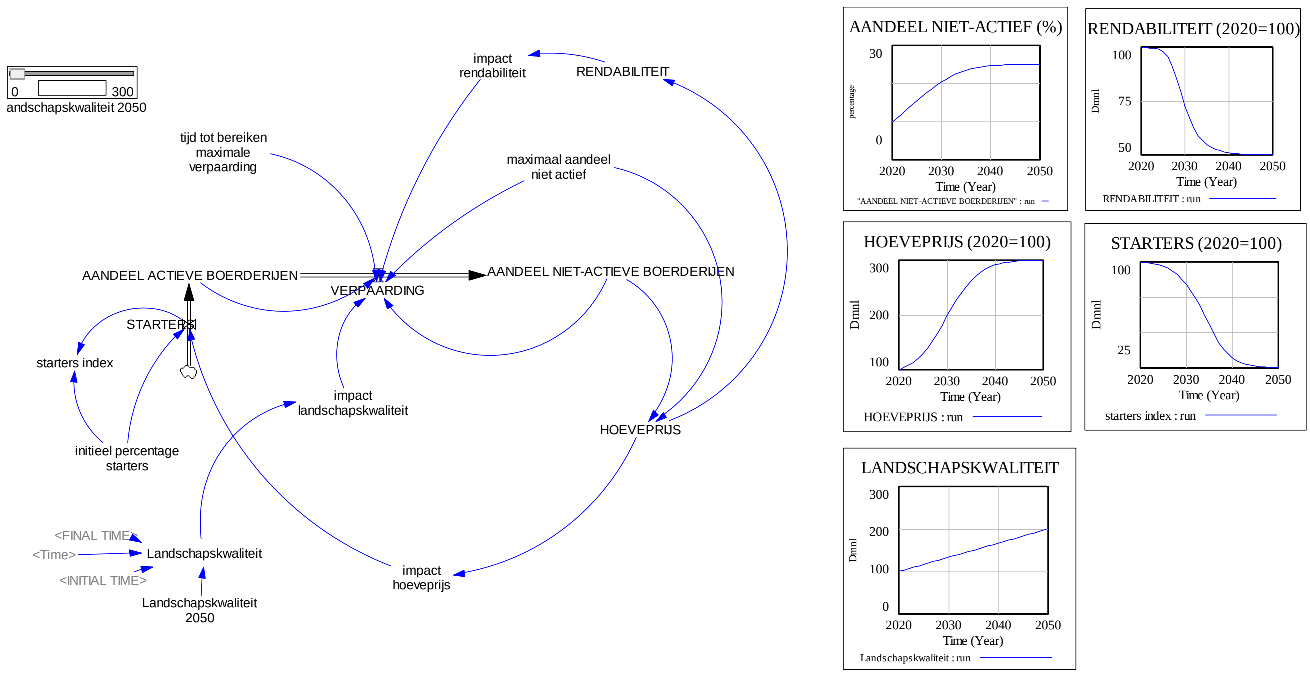

Figure 17 Feedback structure for rural gentrification with key indicators.

The model can be used to examine the mid- and long term pattern of rural gentrification and is useful for integration in a model with a broader scope (nature development, recreation, water management). The key mechanism is the interaction between active farms (with a farming function) and farms used for other purposes (B&B, horsekeeping etc). Ultimately, the stakeholders decided SD modelling of rural gentrification was innovative, but more detail was needed in the model. Further development is an ongoing process, though the model is useful for starting this discussion and clarifying the idea of SD modelling.

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Furthermore, a scenario-driven structure was used to examine the competition between residential, agricultural and natural land use cover (Figure 18). Exogeneous scenarios were developed with the VITO RuimteModel[4] and used to regulate urban sprawl and nature development in the model.

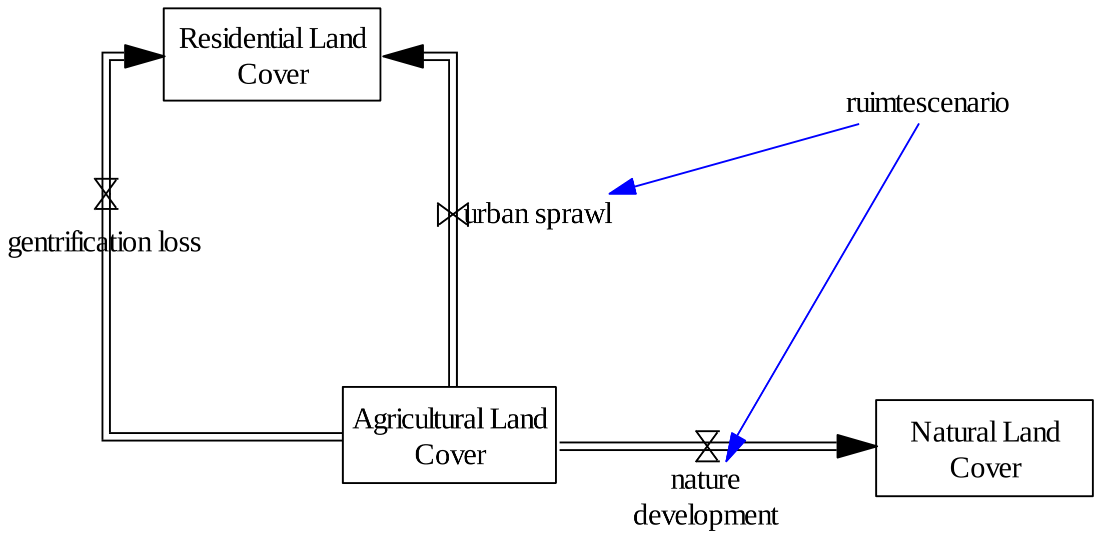

Figure 18 Model structure for land cover change with three stocks.

[4] https://vito.be/en/spatial-model-flanders-ruimtemodel-vlaanderen

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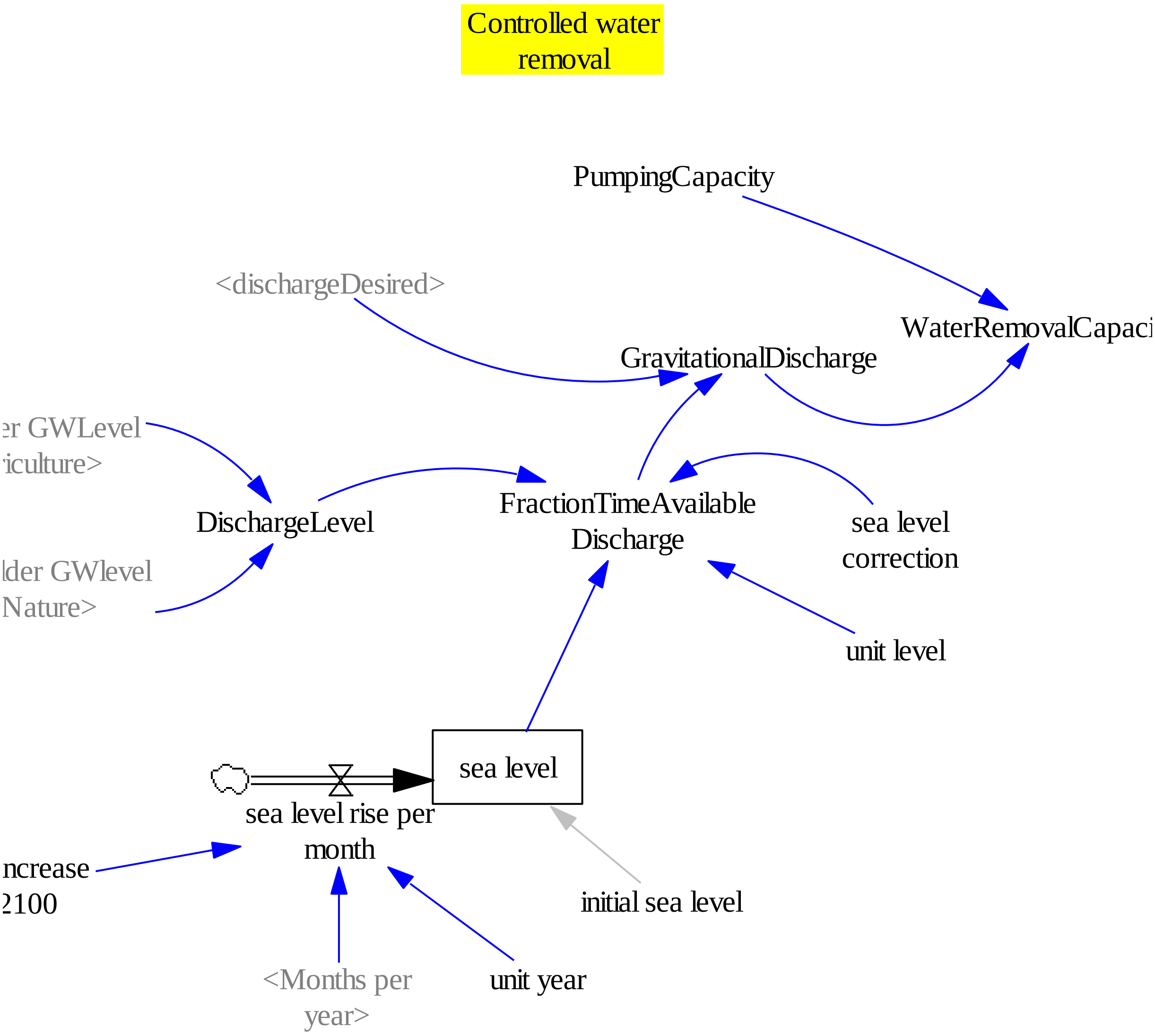

Figure 19 Model construct for the impact of sealevel rise on the operational window for discharging water to the sea as an strategy for water management.

The decommissioning tool of Figure 16 is context-specific – the main generic model construct found in the model is the use of an age-cohort model for the installations, ageing and decommissioning of the wind turbines (**Error! Reference source not found.**). The decommissioning of the turbines depends on the life time of the turbines. The installation plan for the wind turbines (number, initial power and size) as imported as input time series data and can be connected with existing Marine Spatial Plans. A generic equation for the actual number of wind turbines *N(t,T)* in year *t* for age cohort with age *T (*Figure 20*):*

$$N(t,T) = N(t - dt,T) + N(t\text{-}dt,T\text{-}1) - N(t\text{-}dt,T) = N(t\text{-}dt,T\text{-}1)$$

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The number of ageing turbines are either added to the next age class or removed in case the age of the cohort matches the life span for the actual year minus the age of the cohort (by using the scenario for the life span).

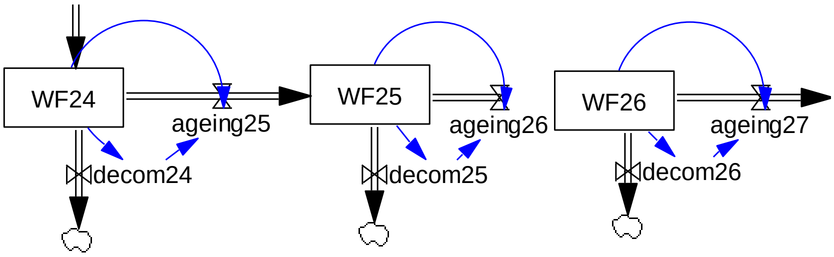

Figure 20: Age-cohort mechanism used for the wind turbined (graphical representation in VenSim).

A second generic element is the model construct used to obtain the annual maintenance costs as a function of the number of turbines, turbine age, turbine power and the Levelized Cost Of Energy in EUR per MWHr.

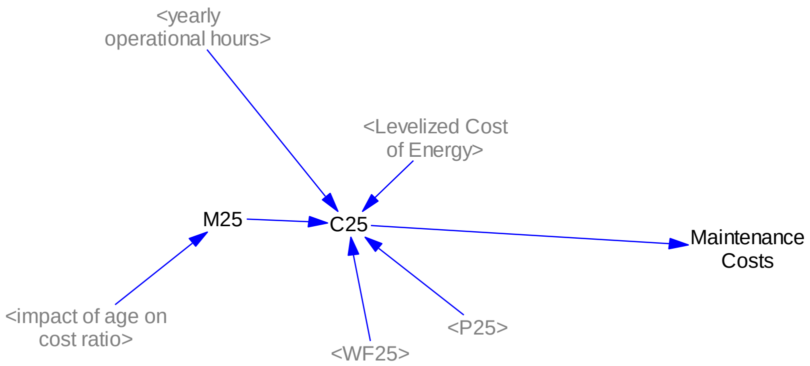

Figure 21 Model construct for turbine maintenance costs (example for turbines of age 25).

Furthermore, different time series corresponding to different scenarios where produced for the planned installation, known life span of the turbines, initial power capacity of the turbines, maintenance costs and demand of offshore and onshore space per turbine taking into account a safety perimeter. These are read from an external spreadsheet, which can be updated or corrected quickly if needed. As an example, Figure 22 shows the standard scenario for the maintenance costs, expressed in terms of the Levelised Costs of Operational Energy or LCOE in EUR/MWhr.

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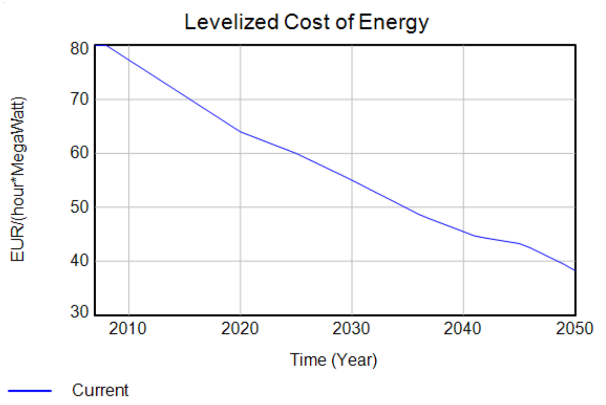

Figure 22: Scenario for the Levelized Cost Of Energy (LCOE) in EUR/MWhr.

The impact of age on the maintenance cost is obtained from a cost-ratio function (Figure 23). This function is then multiplied with the LCOE to calculate the maintenance cost.

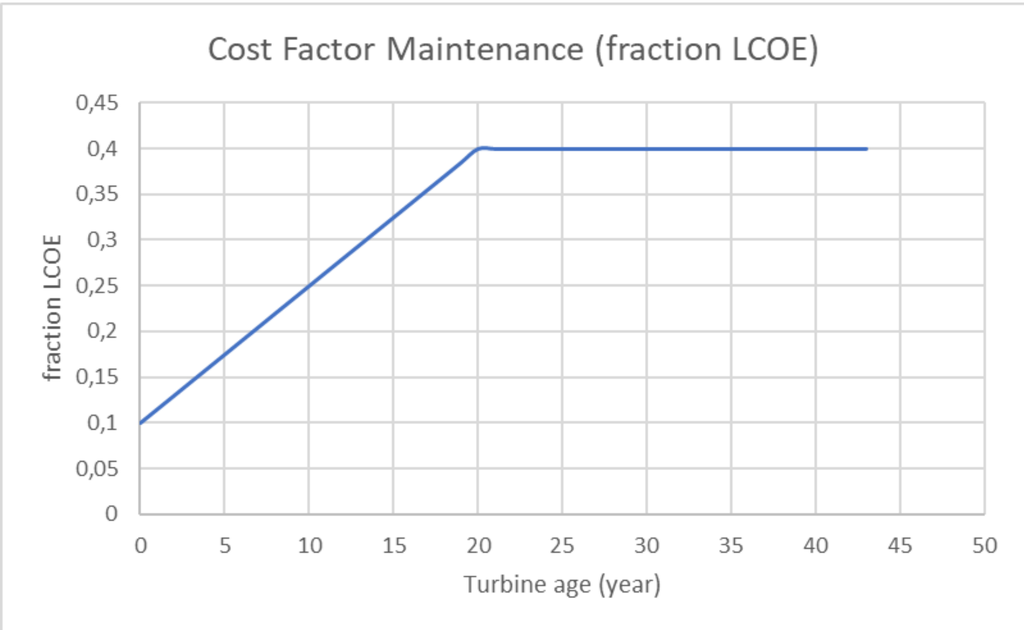

Figure 23: Impact of turbine age on the maintenance costs.

Otherwise, the model uses multipliers to obtain estimates for the impacts on employment and use of space with limited value for a generic toolbox.

Offshore sand mining in the Belgian North Sea is an economic activity and contributes to the sand needed for onshore construction (concrete production). It is a typical example of a renewable resource which can be depleted if consumption exceeds the renewal rate, it is also relevant as environment-economic land-sea

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interaction. A simple model construct was developed to examine whether the issue raised by stakeholders could be covered in the models.

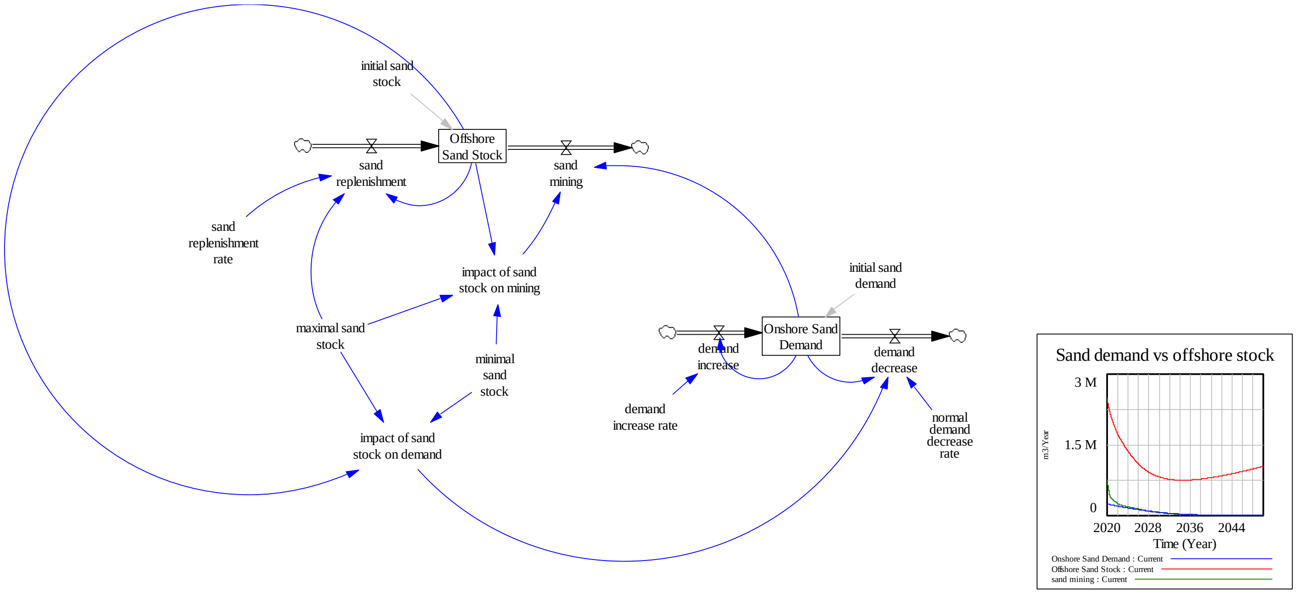

Figure 24 Model construct for offshore sand mining with interaction of demand, resource renewal and resource use.

The model construct can be reused for a different problem context, such as coastal fisheries.

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3.2. MAL02 – SW Messinia

According to our stakeholders, the main constraints for the sustainable development of the area are the lack of trust and cooperation within and among the sectors of economy. From the stakeholder workshops, the aim of the operational model was to show how:

- the restoration and enhancement of ecosystem services in the Gialova Lagoon wetland;
- a shift to more integrated farming practices;
- the current trends of tourism development are putting pressures on land and water resources and the need and possibilities to diversify the tourism product towards thematic sustainable destination tourism

to create the baseline for achieving the common vision for the area (Tiller et al., 2019).

Thus, our approach is based on dividing the whole model into two sub models that when combined connect all the different land-sea interactions that are important for our case. One model focuses on the Gialova lagoon and the pressures on the most sensitive ecosystem of the area, which also supports a viable fishing community. The other sub model focuses on the land uses of tourism and farming, the interactions between them and their relation to the status of the lagoon and the marine environment. The second model is an outcome of the combination of the previously separated sub models of farming and tourism, which were decided to be included in a common view due to the increased links and connections between them.

In modeling the shift towards more integrated farming practice in the submodel, a model structure was identified that can be used more generically. In Figure 25 Farming transition structure for MAL02.Figure 25we illustrate part of Sub-model 2A showing a shift from convential to integrated farming with factors that affect the rate of change from convential to integrated farming. What we highlight here is not generic factors that are affecting farmers' choice to adopt integrated farming practices at an individual level (which relate to the perceptions, regarding costs and knowledge on what is needed), but the transition factors that affect the rate of change at a social level, which relate to policies, subsidies, the price of olive oil and the ability to use technological advances. It is the interaction between the individual and a policy/government level.

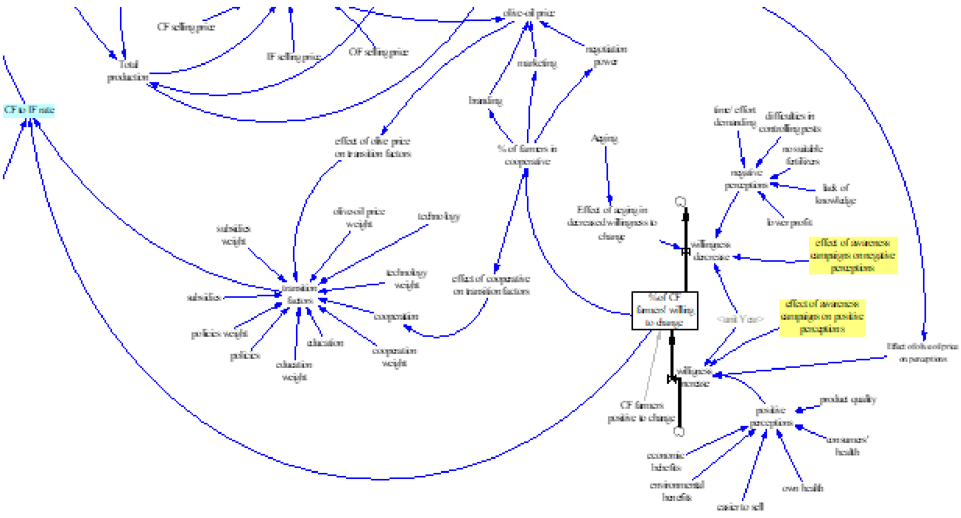

Figure 25 Farming transition structure for MAL02.

This macro/micro level interaction between individual perception and policy operate through cooperatives – as the means for information exchange leading to changes in perception. Cooperatives will also play a major role in providing know how and supporting agronomists for full time farming consultation to all members, support the application of smart agriculture and relevant data management with support from academic experts, take over the task of branding, marketing and promotion under the guidance of relevant expert, resulting in a better quality produce that could be place branded, in which case its price could be up to 5 times higher than it is now, as it was mentioned by local experts.

Cooperatives as structures for information exchange for introducing perception mechanisms in models can be used generically, especially in a farming context or wherever cooperative organizations exist regardless of industry. In this structure, we would see oscillating behaviour between two behaviour processes (rather than information stocks). As new information is available in the cooperative structure, this initiates oscillating behaviour mechanism as the perception of farmers seek (goal seeking) to incorporate this new information (knowledge).

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3.3. MAL03 – Baltic

There is a considerable nutrient loading from land catchment to the Baltic Sea and its coastal areas (Vigouroux et al., 2020 and 2021; Destouni et al., 2021; Chen et al., 2021). As a consequence, the Swedish Norrström drainage basin (a Baltic coastal catchment) 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), as many other parts of the Baltic Sea and also many inland waters, suffer from eutrophication and harmful algae blooms (HELCOM, 2017).The main relevant land-sea interactions for MAL3 are identified and validated by the local and regional stakeholders in a series of sector and multi-actor workshops organized as part of WP1 (Tiller et al., 2019a and 2019b) and are summarized in the unified causal loop diagram (CLD) shown in Figure 26 (including 31 system components with 160 connections resulting in 567 feedback loops).

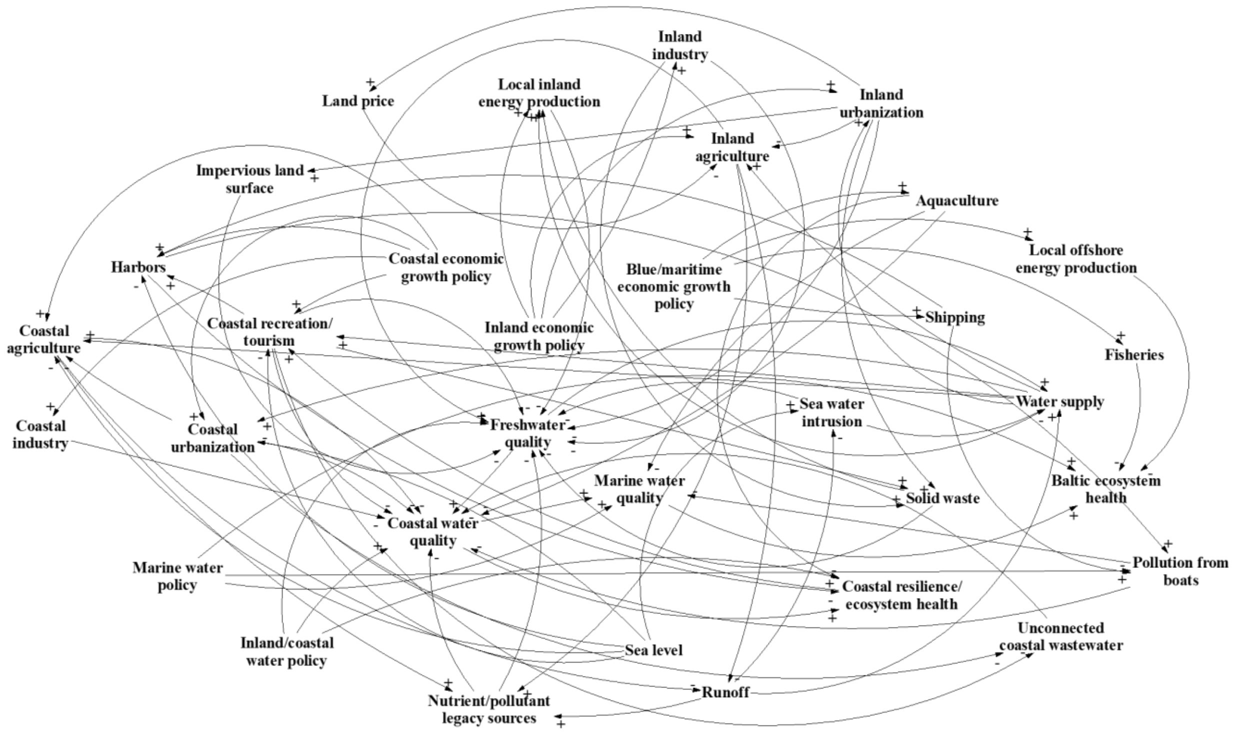

Figure 26: Regional causal loop diagram (CLD) for MAL3. Positive (negative) interactions represent the same/reinforcing (opposite/balancing) change directions for the connecting system components.

To address stakeholder system understanding, the system dynamics (SD) model developed for MAL3 focuses on water availability and quality, and their interactions with and implications for key inland and coastal sectors as a land-sea and sector interaction and impact tracer. Changes in water availability interactions due to climate change and human activities and their development affect coastal water flow and sectoral water availability and exchanges as well as the waterborne nutrient loading to inland and coastal waters, contributing to the eutrophication water quality, and ecosystem status issues on land, in coast and at sea in MAL3. In addition, these impacts create implications for the implementation and effectiveness of various management and eutrophication/pollution mitigation policies and measures for sustainable development in MAL3. Such land-

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sea system characteristics, interactions and impacts are investigated through SD modelling in MAL3 within the two following main themes (Viaene et al., 2020):

- Cross-(sub)system/sector water availability exchanges (quantity model), and their implications for seawater intrusion into and quality of fresh coastal groundwater (quantity and quality perspective), and inland/coastal sector growth and environmental policy; and
- Cross-(sub)system/sector exchanges of waterborne nutrients, their loads through various systems and sectors in the land catchment and into the coastal waters (quality model) and associated sector growth and inland/coastal/marine environmental policy implications.

Two SD sub-models were structured separately for each theme (water quantity model, and water quality model) (de Kok et al., 2019; Viaene et al., 2020 and 2021) and fully quantified using available data, supporting model (results) and other information from relevant reports and peer-reviewed scientific literature (Kastanidi et al., 2018; Seifollahi-Aghmiuni et al., 2020). The two SD sub-models were further connected to develop an integrated MAL3 land-sea system model that is and further will be used to analyse various local/regional change/development model scenarios as well as regionally-downscaled global scenarios of the representative concentration pathways (RCPs) and the shared socioeconomic pathways (SSPs) for MAL3.

Sub-model 1, addressing the cross-(sub)system/sector water availability exchanges theme, investigates inland sectoral and coastal system interactions regarding water flux and availability through natural surface and subsurface water systems and various socio-economic sectors. The complexity of the model is in the stock-flow structure rather than the data and equations, as it involves 10 stock variables with 42 flow/rate variables and more than 70 auxiliary variables. Sub-model 1 addresses the implications of freshwater flow changes due to hydro-climatic and human activity changes (e.g., in urbanization, tourism, agriculture) for seawater intrusion risks into fresh coastal groundwater.

Sub-model 2, addressing the cross-(sub)system/sector waterborne nutrients exchanges theme, investigates contributions of different inland and coastal sectors to the waterborne nutrient (phosphorus and nitrogen) loads through various socio-economic sectors and surface and subsurface inland water flows to the coastal waters. The complexity of the model is related to the data for its quantification rather than its stock-flow structure. Nutrient interactions follow the water exchange interlinkages between resources and water consumers in inland/coastal sectors and natural surface and sub-surface systems. Sub-model 2 is used to evaluate how flow shifts due to possible future changes affect the nutrient loads to inland and coastal waters. It also evaluates sector impacts and possible policy feedbacks driven by changes in coastal nutrient loads.

Figure 27 shows the main feedback loops between key system components (natural water systems and various socio-economic sectors) addressed in the integrated MAL3 SD model. These interactions were identified as important by the MAL3 stakeholders through the co-developed regional CLD. Based on the two structured sub-models and the integrated land-sea system model for MAL3, three generic model constructs can be suggested with reuse potentials, representing some of the feedback loops in the integrated MAL3 SD model, illustrated in Figure 27. These model constructs are explained in the following sub-sections.

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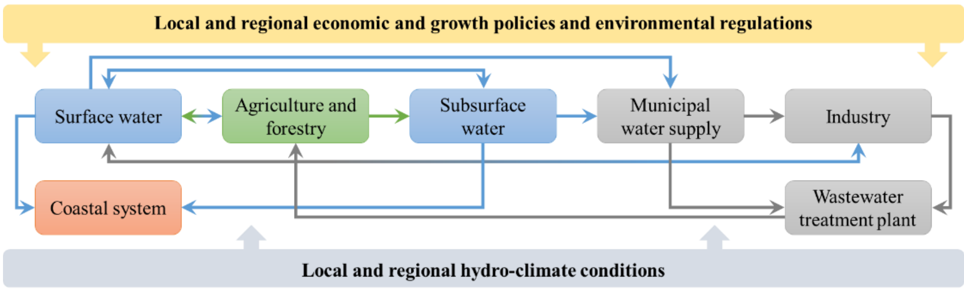

Figure 27: Main feedback loops involved in the integrated system dynamics (SD) model for MAL3. The colour of interactions is assigned based on the box colour of the influencing system component (de Kok et al., 2021).

3.3.1. Agricultural water availability and its interactions with inland and coastal natural sub-systems

This generic model construct can be used to examine the impacts of hydro-climatic and land-use changes on agricultural water availability and corresponding changes in surface and subsurface water flows to the coast. The latter changes are reflected on coastal outflow (i.e. blue water) and affect coastal nitrogen and phosphorus loads (i.e. coastal water quality). In addition, changes in critical seawater intrusion risk in the coast can be assessed in relation to changes in subsurface coastal outflow. The model construct also simulates the resulting changes in green water (i.e. evapotranspiration) and how agricultural contribution to green water could change. The key interactions and feedback structures that are considered as bases for the model development are shown in Figure 28. The associated generic stock-flow model structure is shown in Figure 29.

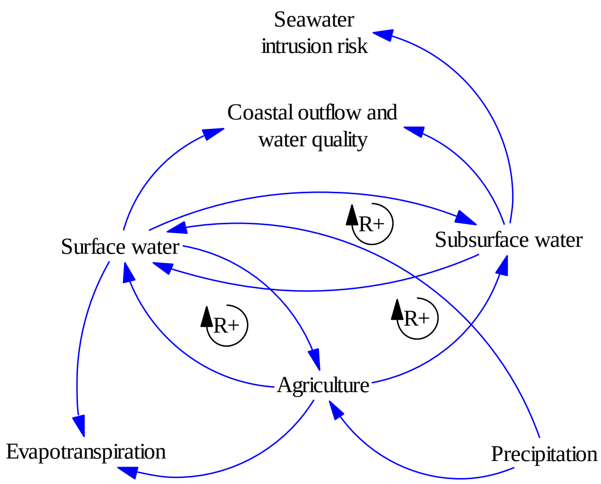

Figure 28: Interactions and feedback structures involved between inland and coastal natural sub-systems and agriculture sector in MAL3. The reinforcing feedback loops are shown with the clockwise circles.

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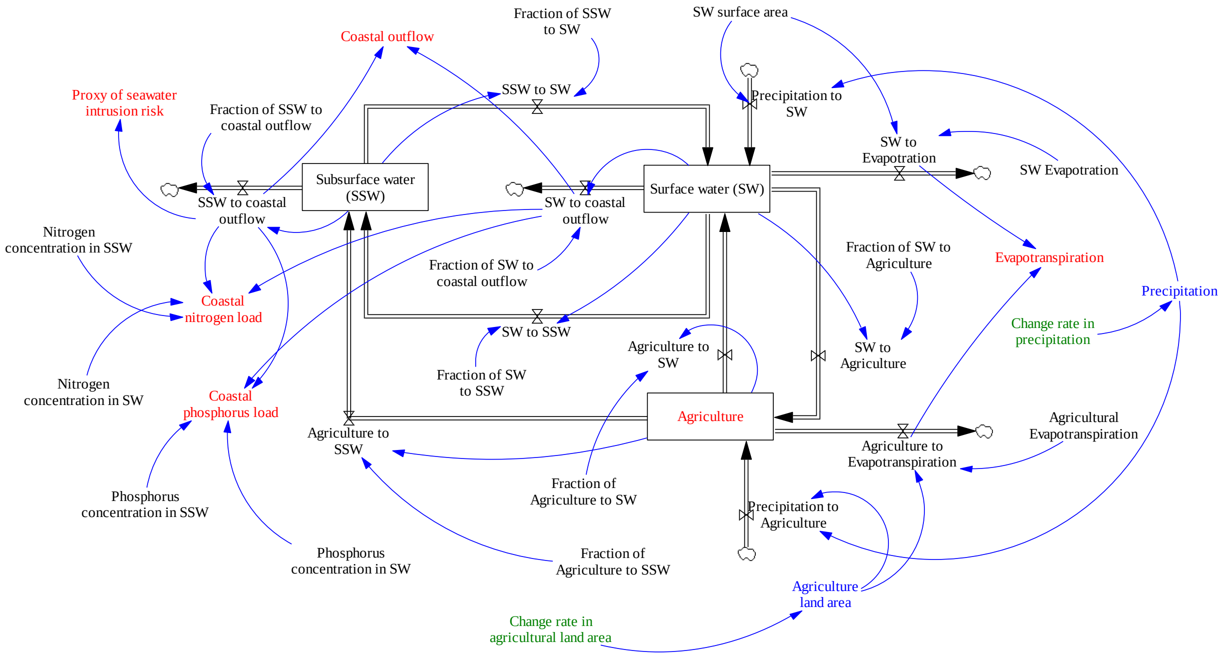

Figure 29: Stock-flow model structure for water availability for agriculture sector and its interactions with inland and coastal natural sub-systems. The main input and output variables are shown in blue and red, respectively. Change driving variables are shown in green in relation to hydro-climatic and land use changes.

In this model construct, the key outputs are coastal outflow, coastal nutrient (nitrogen and phosphorus) loads, agricultural water availability (shown as a stock variable in Figure 29), evapotranspiration, and the proxy of seawater intrusion risk. The key inputs are precipitation and agricultural land area. The change driving variables are defined as change rates in the two input variables (shown in green in Figure 29). The model is set up with annual time steps and its application is exemplified in MAL3 for the projected annual precipitation changes under climate scenario of RCP4.5 (as a more consistent scenario with current and ongoing climate conditions in MAL3) together with the expected annual change in agricultural land area under SSP1 (representing a high level of land-use change in MAL3) during the period of 2010-2100. These changes are shown in Figure 30.

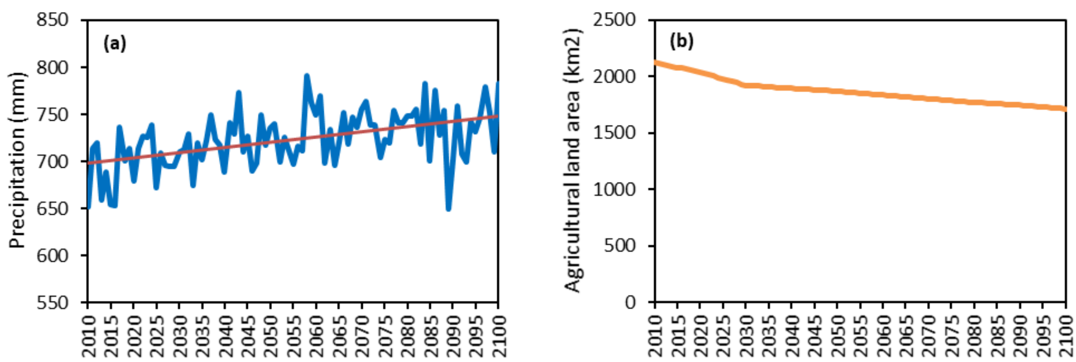

Figure 30: Changes in driving variables of (a) precipitation for climate scenario RCP4.5, and (b) agricultural land area for SSP1, used to demonstrate the application of the generic model construct for agricultural water availability in MAL3.

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Regional precipitation projection for RCP4.5 (Figure 30-a) shows an increasing trend during 2010-2100 (Swedish Metheorological and Hydrological Institute (SMHI), https://www.smhi.se/en/climate/future-climate/climate-scenarios/). Also, agricultural land area in the MAL3 coastal catchment (Figure 30-b) decreases with an average rate of 12% for SSP1 during 2010-2100 (International Institute for Applied Systems Analysis (IIASA), https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10). The results of model application are shown in Figure 31.

Annual variations in agricultural water availability (Figure 31-a) are mainly driven by hydro-climatic (precipitation) changes in this generic model construct. Based on the stock-flow structure shown in Figure 29, agricultural water is supplied through surface water and precipitation, with latter also affecting surface water availability in the system as well as the interactions between surface and subsurface waters. These impacts drive annual variations in agricultural water availability. Relevant business analysis should take into account such interactions, impacts and changes in the system regarding agricultural water availability, to decide about the application of proper farming practices and/or agricultural development.

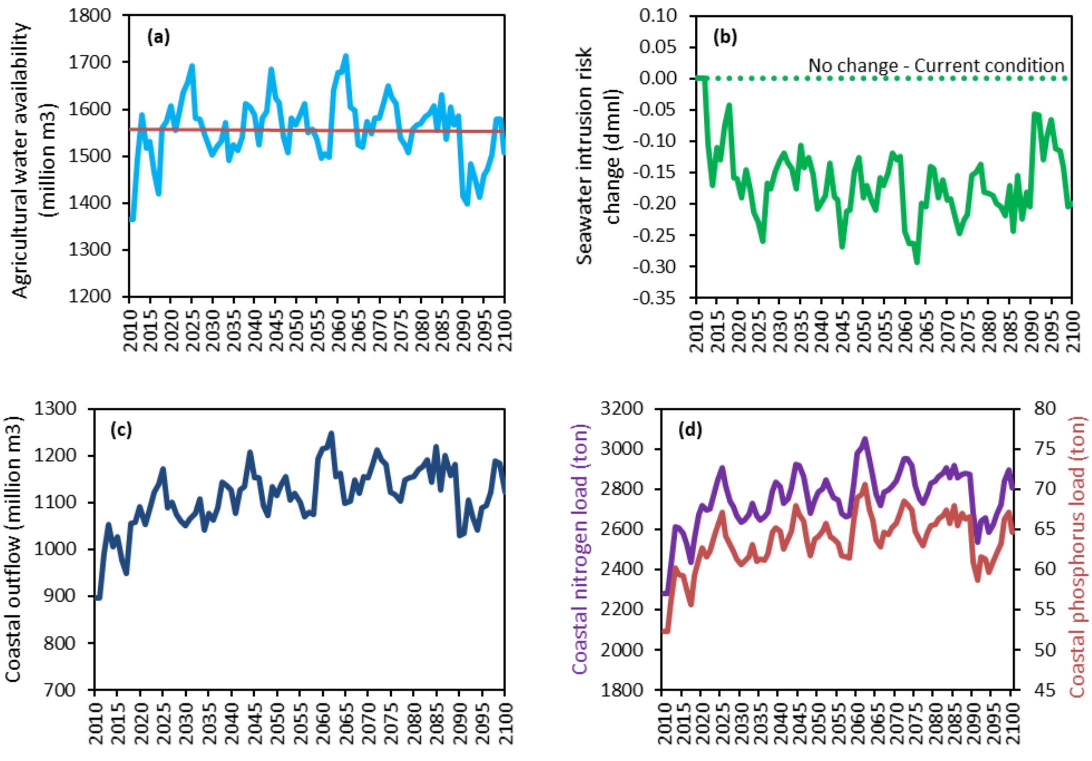

Figure 31: Demonstration results of the generic model construct for agricultural water availability under RCP4.5 and SSP1 change scenarios in MAL3: (a) agricultural water availability, (b) seawater intrusion risk, (c) coastal outflow, and (d) coastal nutrient loads.

Proxy of seawater intrusion risk is a management indicator, formulated as below in the generic model structure presented in Figure 29 (Seifollahi-Aghmiuni et al., 2020):

$$Proxy\ of\ seawater\ intrusion\ risk = 1 - \frac{Q_{SDG2}}{Q_{SDG1}} \quad (3\text{-}3\text{-}1)$$

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where, Q_{SDG1} and Q_{SDG2} are submarine groundwater discharge to the sea under the current condition and a new changed condition, respectively. Zero value for this indicator means no change in the current seawater intrusion risk while positive (negative) values are associated with higher (lower) risks compared with the current condition. Figure 31-b shows that for the tested hydro-climatic and land-use changes, the annual risk of seawater intrusion in coastal fresh waters will be lower than that of for the current condition in MAL3.

Annual variations in coastal outflow (Figure 31-c) is driven by the interactions between natural sub-systems and agriculture sector, and define annual variations in coastal nitrogen and phosphorus loads (Figure 31-d). These loads are calculated as the multiplication of the coastal outflow through surface and subsurface waters and associated nitrogen and phosphorus concentrations with those flows. Since nutrient concentrations are considered constant in the generic model construct (with lower phosphorus concentrations than nitrogen concentrations), the loads follow the same annual change pattern as coastal outflow. Changes in coastal nutrient loads can be used to evaluate the effectiveness and implementation of environmental policies and regulations for possible future conditions.

3.3.2. Water availability for urban and tourism sector and its interactions with inland and coastal natural sub-systems

This generic model construct can evaluate the impacts of hydro-climatic and land-use changes on urban and tourism sectors regarding water availability, storm water runoff and wastewater handling. It also simulates the interactions with surface and subsurface waters and how their possible changes are reflected on coastal outflow (i.e. blue water) and quality as well as seawater intrusion risk in coastal fresh waters. Evaporation from surface water and urban storm water runoff can also be calculated in this model construct. The key interactions and feedback structures considered in this generic model structure are shown in Figure 32. The associated generic stock-flow model structure is shown in Figure 33.

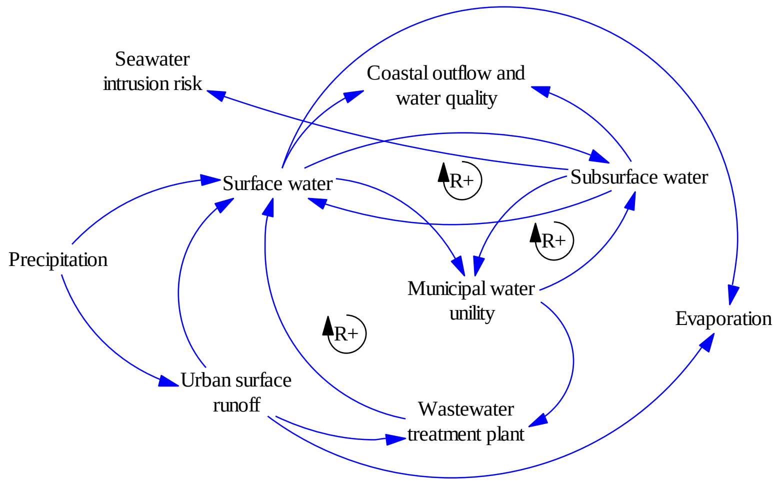

Figure 32: Interactions and feedback structures involved between inland and coastal natural sub-systems and urban and tourism sectors in MAL3. The reinforcing feedback loops are shown with the clockwise circles.

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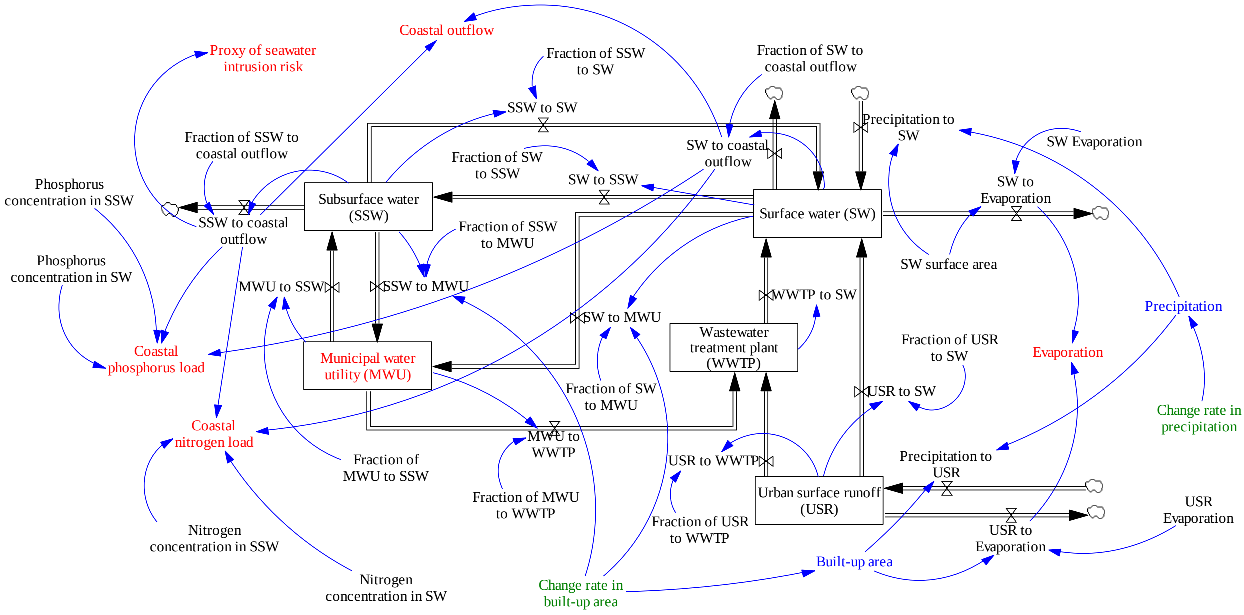

Figure 33: Stock-flow model structure for water availability for urban and tourism sector and their interactions with inland and coastal natural sub-systems. The main input and output variables are shown in blue and red, respectively. Change driving variables are shown in green in relation to hydro-climatic and land use changes.

In this model construct, the key outputs are coastal outflow, coastal nutrient (nitrogen and phosphorus) loads, municipal water availability (shown as a stock variable in Figure 33), evaporation, and the proxy of seawater intrusion risk. The key inputs are precipitation and urban (built-up) land area. The change driving variables are defined as change rates in the two input variables (shown in green in Figure 33). Similar to the generic model construct on agricultural water availability, this model is also set up with annual time steps and its application is exemplified in MAL3 for precipitation changes in RCP4.5 (Figure 30-a) together with changes in urban land area in SSP1 (with an average increase rate of 55% - Figure 34) during the period of 2010-2100. The results of model application are shown in Figure 35.

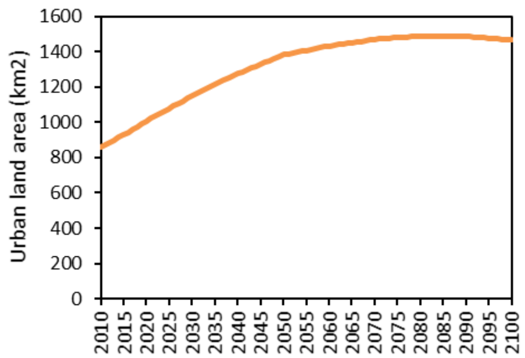

Figure 34: Changes in urban land area for SSP1, used to demonstrate the application of the generic model construct for water availability for urban and tourism sector in MAL3. Source: IIASA, https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10

Figure 35-a shows an increasing trend in municipal water availability, due to urbanization (Figure 34) and increased water demands in urban areas, as well as an increasing trend in urban storm water runoff, driven

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by the expansion of impervious land surfaces and increased precipitation (Figure 30-a). These changes affect surface and subsurface waters and their contributions to coastal outflow (Figure 35-c), which also lead to changes in seawater intrusion risks (to be lower than the current condition in MAL3 - Figure 35-b). Annual changes in coastal nutrient loads follow the same pattern as coastal outflow with lower phosphorus loads than nitrogen (Figure 35-d), as phosphorus concentrations are lower than nitrogen. Simulated changes in municipal water availability and urban storm water runoff can be used in spatial planning and analysis in urban areas, to decide about the regional potentials for further urbanization and the capacities of urban storm water and wastewater handling.

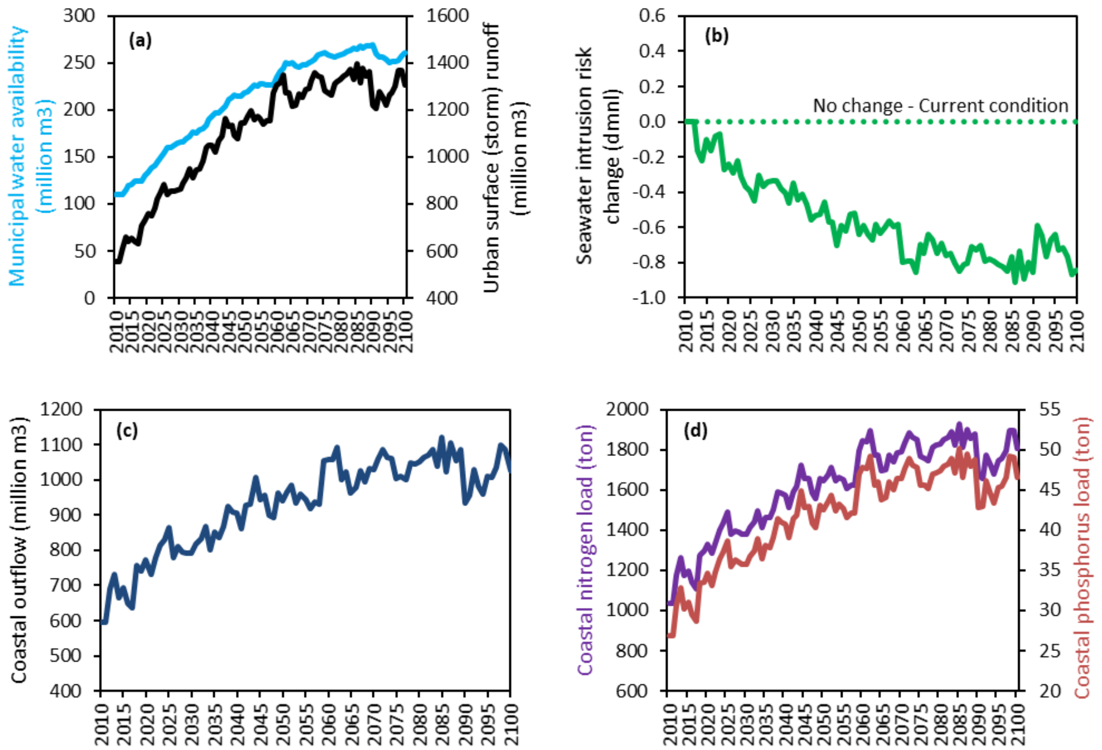

Figure 35: Demonstration results of the generic model construct for water availability for urban and tourism sector under RCP4.5 and SSP1 change scenarios in MAL3: (a) municipal water availability and urban storm water, (b) seawater intrusion risk, (c) coastal outflow, and (d) coastal nutrient loads.

3.3.3. Implementation of environmental regulations on coastal water quality

This generic model construct (Figure 36) simulates coastal waterborne nutrient (nitrogen and phosphorus) loads from current inland and coastal sectoral activities (i.e. active/point sources) and historical nutrient legacies (i.e. diffuse sources). These loads are driven by surface and subsurface outflows to the coast, contributing specific amounts of phosphorus and nitrogen (associated with their monitored/estimated concentrations) to the total coastal nutrient loads. The model construct also includes two policy indicators in relation to any environmental regulations or policies (e.g. the Baltic Sea Action Plan (HELCOM, 2007 and 2021) for MAL3), addressing their implementation in coastal areas. For this, the total phosphorus and nitrogen loads to the coast are compared with the policy-given target loads, and associated indicator is calculated as:

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$$Policy\ indicator = \begin{cases} \dfrac{Load - Target}{Target} & if \quad Target > 0 \\ \dfrac{Load}{INT(Load)} & if \quad Target = 0, Load \geq 1 \\ Load & if \quad Target = 0, Load < 1 \end{cases} \quad (3\text{-}3\text{-}2)$$

where, $Load$ and $Target$ are total phosphorus or nitrogen loads to the coast and their target load values defined in the considered environmental regulation or policy to assure good water quality and ecological status in coastal areas and corresponding marine environment, respectively. Zero values for these indicators show that the policy-given target loads are achieved while positive (negative) values show higher (lower) nutrient loads than the defined target values – i.e. worse (better) water quality condition than planned for in the considered environmental regulation or policy.

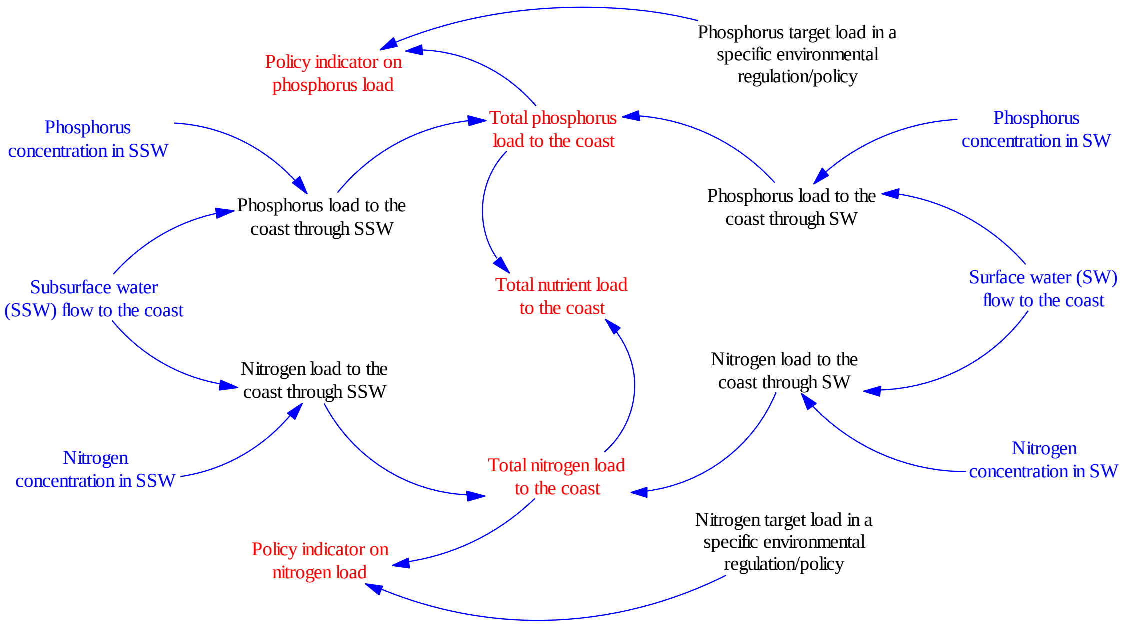

Figure 36: Stock-flow model structure for evaluating the implementation of environmental regulations/policies on coastal water quality. The main input and output variables are shown in blue and red, respectively.

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3.4. MAL04 – Charente

3.4.1. Water resources and uses

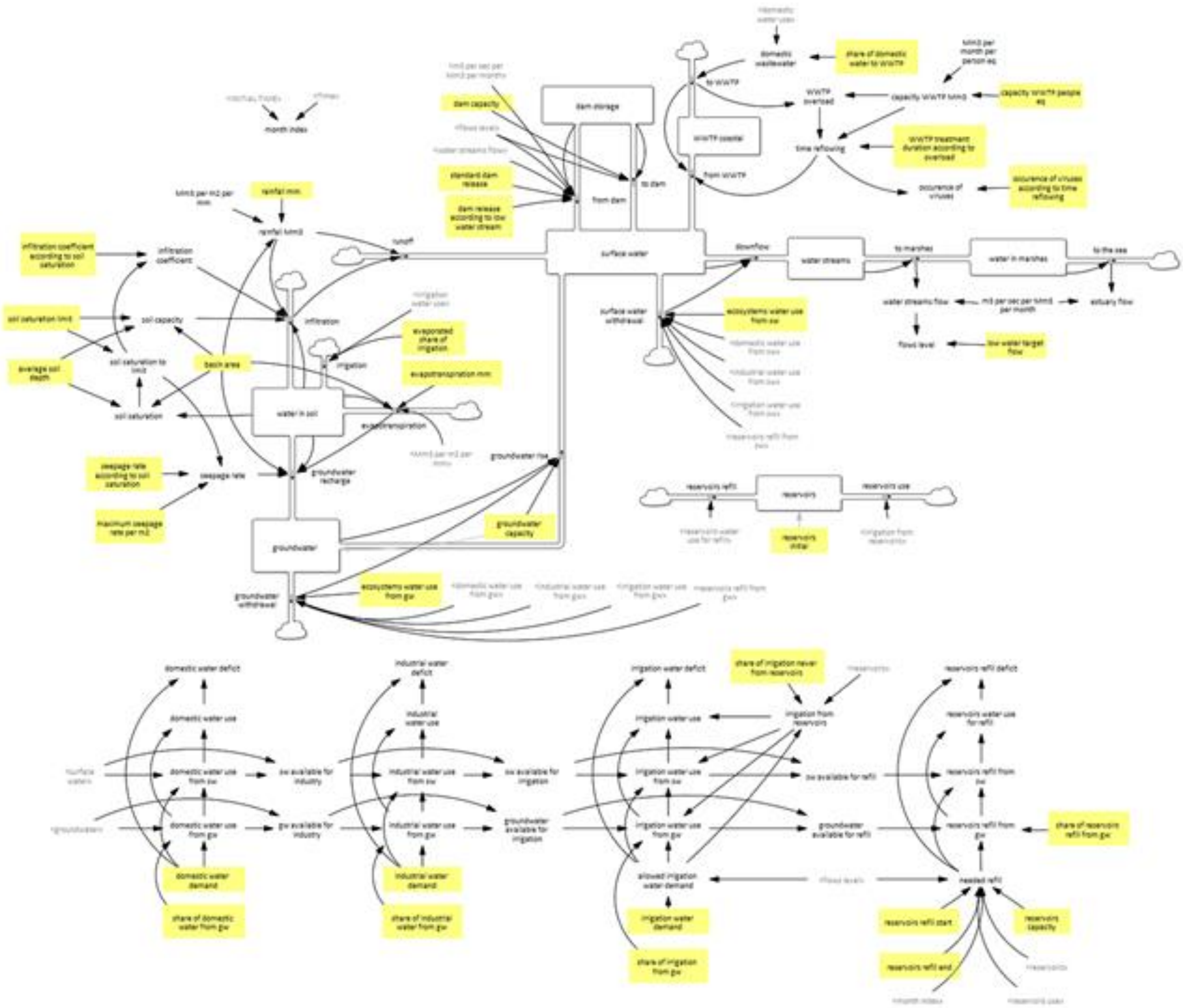

Figure 37: Generic SD water model. Inputs are in yellow.

The generic water SD model simulates the links between surface and groundwater bodies and their interactions with domestic, agricultural and environment needs. The absence of spatial detail, the lack of observations about some water stocks and the difficulty to consider time delays limit its accuracy. Nevertheless, it can serve to develop water models adapted to specific conditions and used as a basis for discussion with stakeholders. It allows evaluating causal relationships between the water cycle, water uses by population and activities, regulations and relevant climate parameters such as rainfall and temperature, considered through evapotranspiration.

It roughly represents the water cycle (on a one-month basis), keeping the flows and compartments that seem most relevant in this complex cycle (cf. figure below) and encompassing natural and built-up water cycles. The model connects surface water (water streams, lakes and reservoirs), groundwater, marshes and coastal waters. The model also includes a subpart on wastewater treatment. The stock variables representing theses

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quantities are expressed in million cubic meters (Mm^3). Over time, these compartments exchange water through different simplified physical processes. Flow variables represent these exchanges in Mm3 per month.

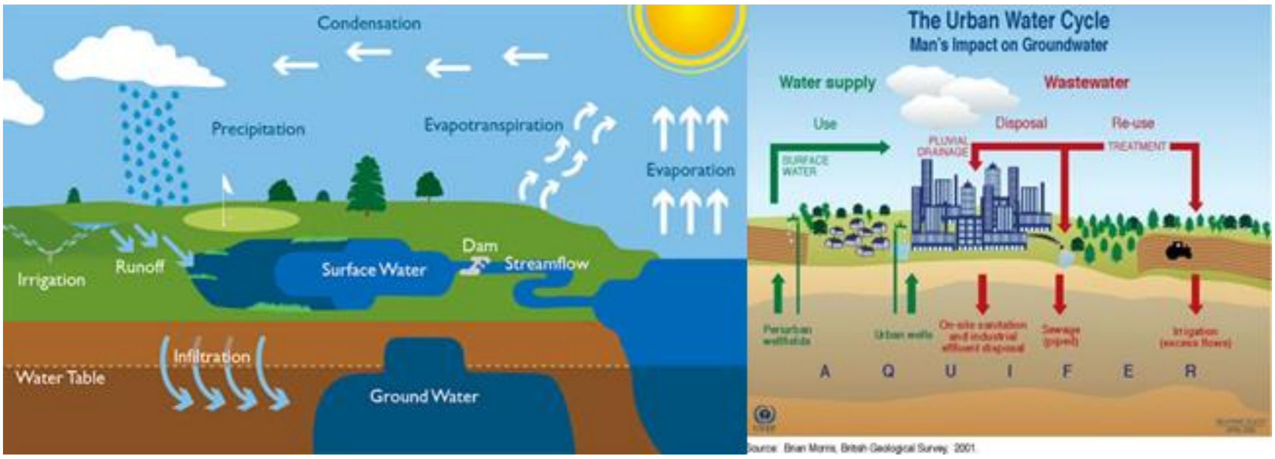

Figure 38: Illustration of the general water cycle.

Main outputs of the model are the available water for different uses, which depends on threshold flows needed for the good functioning of aquatic ecosystems (Q10 flow) and abstraction permits (irrigation), the concentration in trophic resource in coastal waters and the coastal salinity (relevant for shellfish farming and aquaculture). Because the issue of water availability is seasonal, the model uses a monthly basis to highlight water shortages in summer, when rainfall is scanty, irrigation is intensive, and the tourist population reaches its peak.

Considering the natural water cycle starting from rainfall (input data), rainwater either infiltrates to the soil or runs off to surface water. The share of rainwater infiltrating the soil is represented by an infiltration coefficient that depends on soil saturation (in Mm^3 of water per cubic meter of soil) and should be adapted to local conditions. The more saturated is the soil, the less water infiltrates. The amount of water running off to surface water is then equal to rainfall minus infiltration. At the same time, evapotranspiration (input data) and groundwater recharge empty the soil. The water that is not evaporated reaches the aquifers at a seepage rate that depends on soil saturation and local conditions, notably the types of soil present on the territory. Variation in the water table work as follows: when the groundwater bodies are saturated, water rises to surface water, which is characteristic of regions with shallow or alluvial aquifers with low inertia. The groundwater capacity is a calibrated parameter since this value is not actually measured and data are scarce. The amount of rising water is equal to the groundwater amount minus the groundwater capacity when this difference is positive (otherwise, it is null). In the end, surface water reaches the marshes and sea.

Considering activities, water is withdrawn from groundwater and surface water for irrigation, domestic and industrial uses, and to refill reservoirs and dams. For each use, its total demand and the share of water coming from ground or surface water are fixed with observed data. As a result, the model calculates five water demands (one per use) from both the aquifers and surface water. In the case of agriculture, a share of the irrigation water demand is also met by using water from the reservoirs, which refill during winter, until they are empty. Then, for each source stock (groundwater and surface water), demands are met up to the current level of the stock, given that domestic use has the priority over irrigation and reservoirs refill. In addition, irrigation water demand is not met at all if, during a month, the simulated water streams flow is below a fixed threshold for water streams (low-water target flow). Summing over stocks the levels to which the demands are met gives the amounts of water that are withdrawn every month for each use. Note that for a given use, a deficit from one stock is not compensated by another stock, e.g., when the agricultural demand from

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groundwater is not met, it is not compensated by withdrawals from surface water. The dam serves to regulate the water streams flow and functions as follows: when the simulated water streams flow is above the threshold, the dam refills; when it is below, the dam releases water. The refill and release rates of the dam are set using local data.

In addition, a subpart of the model aims to simulate in a simple way a main issue in the urban water cycle that is the capacity of plants to properly treat the wastes released into the natural environment. In this submodel, the wastewater flowing into the treatment plant (WWTP) is a fixed share of domestic water use, as calculated in the water cycle (cf. above). The released water flow is modelled with a fixed delay of the inflow. The duration of the delay (duration of the treatment) depends on the difference between the inflow and the capacity of the WWTP. The capacity of the WWTP, usually expressed in population-equivalent, is converted in a flow capacity (in Mm3/month). When the entering flow is above the capacity, an overload is calculated (the water inflow minus the capacity) and the treatment duration decreases as the overload increases. The shorter is the duration, the less effective is the plant, affecting virus contamination in marine waters.

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3.4.2. Aquaculture production and marine environment

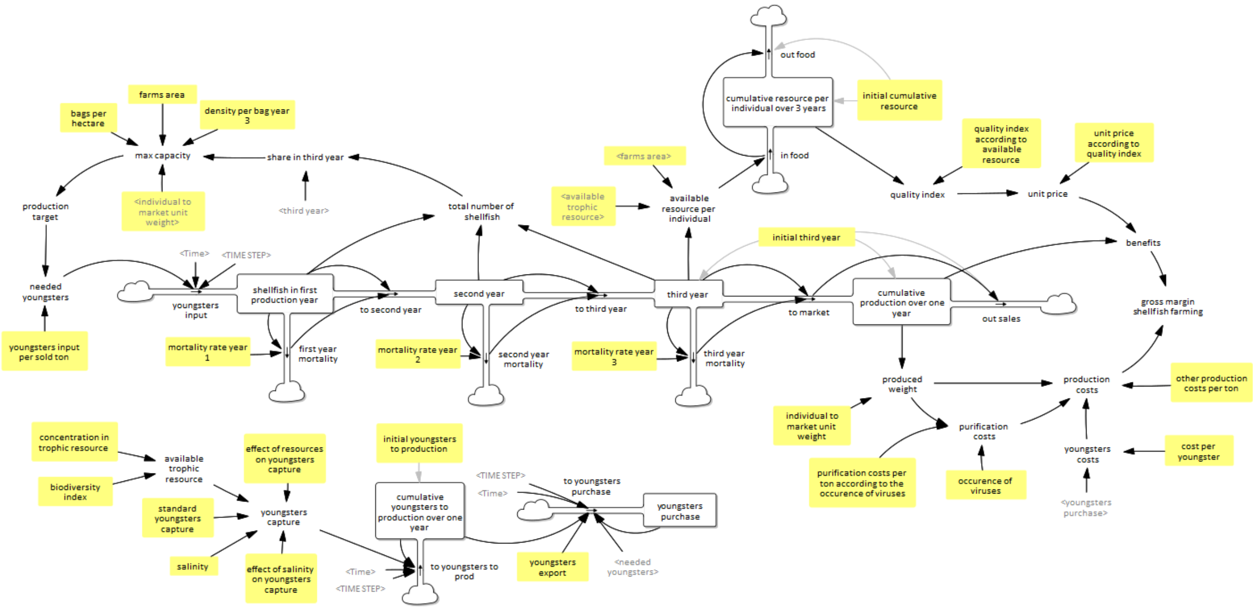

Figure 39: Generic SD shellfish farming model. Inputs are in yellow.

The generic shellfish SD model simulates shellfish production, with the quality of the marine environment affecting primary production, the capture of spats and the breeding and mortality of shellfish. While the model has been developed for oyster farming, this generic version could be adapted to marine farming in general, shellfish farming or even fish aquaculture, given that this latter seems more complex than shellfish farming and may require a substantial adaption of the model.

The dynamic hypothesis that shape the structure of the generic model are that the capacity to yield high quality shellfish depends on water quality in the marine environment and on production techniques. The better the water quality and the less intensive the production, the higher will be the quantity of spat captured and the quality of sold shellfish.

A biodiversity index (in the range 0 to 1 in the generic version), salinity, the availability of trophic resources and the presence of virus describe environmental conditions. All these variables may be linked to some coastal or upstream activities when coupling the model within a larger integrated model. In the generic model, they influence the capture of youngsters, the quality of the final products and purification costs. The quality of products is also related with the husbandry methods (technics used for rearing shellfish or breeding fishes) highlighting the density issues affecting growth (number of oysters per bag and type of bag, mussels per rope or fish per cage, for example). The model also considers marine spatial planning issues that bound the total production capacity. Shellfish farming is a highly regulated activity with leasing ground areas under regulations and in conflict for space with other coastal activities, notably tourism.

Considering a three years production cycle (the number of years should be adapted to the studied aquaculture), the total number of shellfish is at time *t* the sum of three stocks: first production year, second year and third year. Every month, aquaculture products die according to a mortality rate per stock, decreasing each stock. Observed historic data may be used for past mortality rates while future rates can be simulated according to a lookup in relation with marine environmental factors (viruses, salinity, nitrogen or phosphorus concentration, eutrophication...). Flow variables transfer the surviving aquaculture products to the second year and third year stocks. At the beginning of the first year, youngsters are put in production. At the end of

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the last production year, final products are sold. The underlying assumption is that the entire products ready for sale are homogeneous and of the same selling category, which allows easily converting numbers of aquaculture products to tons, the usual unit for data.

Given the total number of aquaculture product and the available trophic resource in the coastal marine environment, the cumulative resource per organism is calculated over n years. This value is then used to calculate a quality index using a lookup. Production costs can be calculated using average values per ton of shellfish products sold. A lookup is used to represent the effect of quality index on the selling price thus allowing calculating the gross margin of the aquaculture product. Similarly, a lookup describes how many youngsters are caught according to trophic resources and salinity. Considering that coastal marine biodiversity influences the available fraction of the trophic resource, we use a theoretical biodiversity index ranging from 0 to 1 (good qualitative biodiversity).

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3.4.3. Transition to sustainable farming

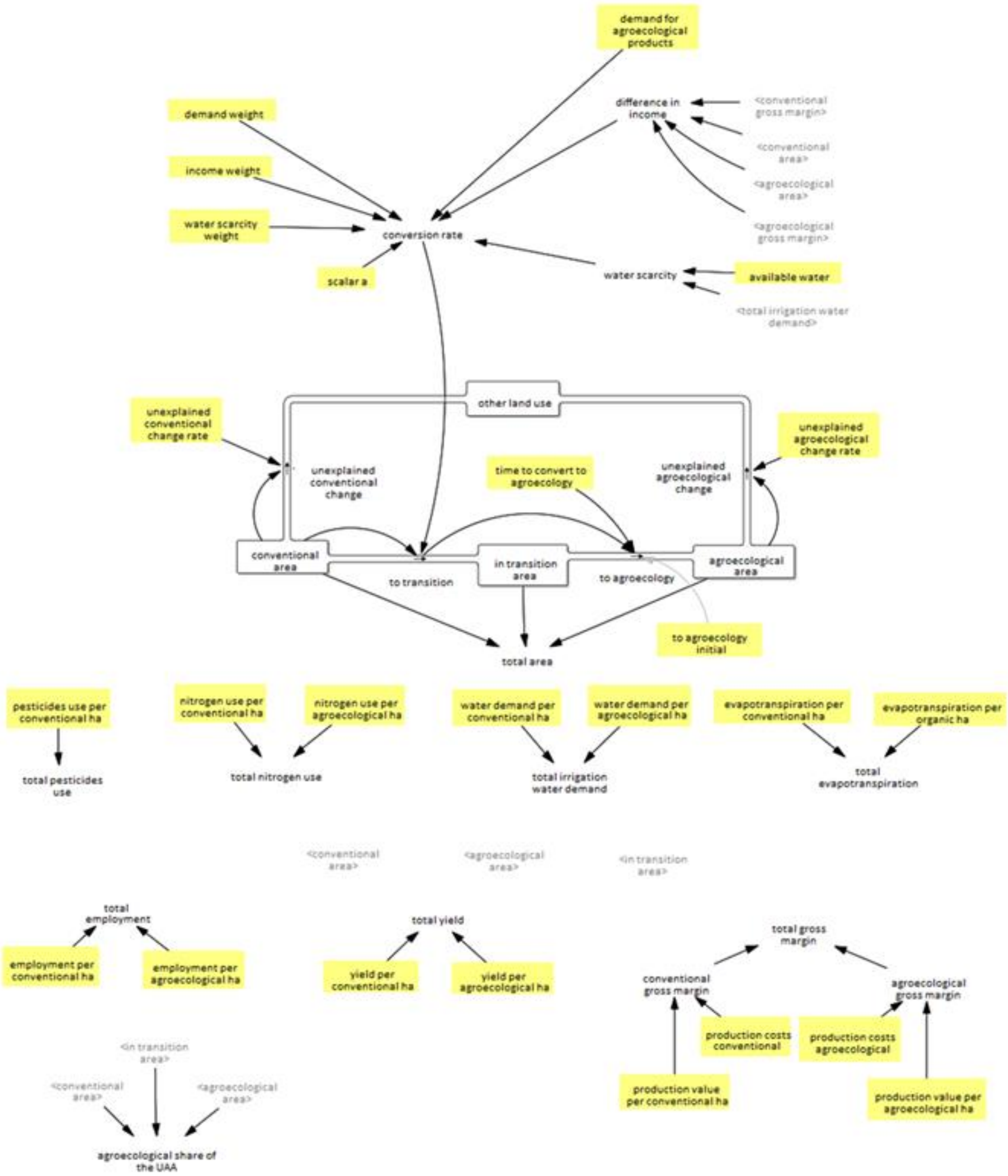

Figure 40: Generic SD agricultural transition model. Inputs are in yellow.

The generic SD model on the transition of agricultural areas to a sustainable farming model (agroecology or organic farming are examples) aims to explain the influence of different drivers of this transition while tracking the socioeconomic and environmental effects of this transition. The number and types of considered drivers should be adapted to the studied territory, representing levers on which policies can act. Quantifying the expected effect of alternative policies on these drivers in scenarios then allows identifying how effective these policies may be. The generic version of the model considers three drivers that should be relevant in most cases: the demand for agro-ecological products, the difference in producer income and water scarcity.

The underlying dynamic hypotheses of the model are that agriculture will convert towards sustainable farming at a speed and up to a level that depend on how favourable are the socio-ecological and market conditions. The development of adapted supply chains and interactions between producers can also accelerate the

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transition process. As sustainable farming develops, regulations and water availability will become less constraining, which may temper the farmers' will to convert.

In the model, three stocks represent the total conventional area, in transition area and sustainable area. During the transition period (of usually 3 years), sustainable practices are already applied but products cannot be sold as sustainable and therefore are still sold at conventional prices. The conversion from conventional to sustainable agriculture is then modelled with flow variable that transit the areas from a stock to another according to a conversion rate (in ha/year). This conversion rate is calculated according to the values of *N* drivers with the following formula:

$$r(t) = a \prod_{i=1}^{N} d_i(t)^{w_i}$$

where *t* is time, *r(t)* is the conversion rate, *a* is a constant (calibrated), $d_i(t)$ is the value of driver *i* and the weight w_i (calibrated) represents the relative influence of driver *i* in explaining the value of *r(t)*, with the sum of all the weights equal to 1.

This modelling is useful to understand decisions that depend on multiple factors, like the transition to sustainable agriculture, as the weights w_i allow assessing drivers' influence. The weights' values should be calibrated using historic data in order to estimate how the considered drivers influenced agriculture's transition in the local context of the studied territory. The scenario analysis will usually assume that these weights will remain constant. However, they may be reviewed to reflect changes in decision paradigms.

The three drivers in the generic model are quantified as follows:

- The demand for sustainable products is a percentage of the total demand for agricultural products, quantified with exogenous data.
- The difference in producer income is the ratio of the sustainable gross margin per hectare to the conventional one, both calculated in the model (cf. below).
- The water scarcity is the share of the irrigation water demand that cannot be met when not enough water is available. The model calculates the water demand (cf. below) while the available water is exogenous. Note that this latter can be calculated by the previous generic SD model on water resources and uses.

All these drivers have a positive effect on the conversion of agricultural areas towards sustainable farming since when they increase, areas should convert faster, and inversely.

While conventional, in transition and sustainable areas evolve over time, the following indicators are calculated using data per hectare of type of farming:

- Irrigation water demand and evapotranspiration, for evaluating the quantitative impact on water resources.
- Nitrogen and pesticides uses, as potential proxies of soils and water pollution.
- Yields, in tons and euros, and gross margin, as economic indicators.
- The employment need, to understand the effect on the territory's social development.

The model can be refined to calculate all these indicators per type of culture (cf. MAL4 version in D14).

As the indicators related to water and gross margin serve to calculate some drivers of transition, feedbacks occur in the model. These feedbacks can be enriched by coupling the model with other models in order to, for

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instance, understand how agriculture interacts with other activities around water, its availability and its distribution.

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3.5. MAL05 – Danube Mouths and Black Sea

The goal of MAL 5 model is to explore alternative scenarios to improve the quality of life and sustainability within the Danube Delta Biosphere Reserve and its marine waters (Black Sea) as one of the most impacted areas along the Romanian littoral. Land-sea interactions in the coastal MAL5 region were identified through separate sector workshops and a combined multi-sectoral workshop as part of WP1 in the COASTAL project. Land-sea interactions are at the core of our study case.

3.5.1 Rural tourism

An important generic model structure was identified in the first meetings with stakeholders held together with experts in the field of tourism, which had as main theme "Rural tourism, leisure and other rural activities" and "Rural development". This led to the initial CLD diagram as they were described in the deliverable, *"D13 Pilot SD Models for Coastal-Rural interactions"*. For both rural and coastal tourism, the meeting outputs were similar outlining that tourism has significant potential as a driver for growth for the local economy.

The protected areas' restrictions will however limit its growth, which is usually accompanied by significant changes. Thus, the need for ecotourism was emphasized, as well as its diversification (*touristic activities*) leading to slow tourism, benefiting the protected area (*biodiversity*) and local people (*workforce*). Destination planning and development strategies (*marketing*, *social events*) are important steps towards the greening of tourism.

Subsequently, holding other meetings with tourism stakeholders, based on their views and perspectives on the importance of the purpose of the obtained model, which is to determine how far the rural tourism of the area can be developed without damaging the balance with the environment the model was further developed. Among the main variables included in the model presented below (Figure 70), we can mention, in particular: ***number of tourism*** (stock variable), tourism pressure, tourism carrying capacity, employment factor, marketing budget, emergency level and time until the emergency level is reached, tourism development and tourism decline.

The development of the tourism model includes representative data for an administrative territorial unit, the Tulcea County area, in order to maintain the accuracy and the significance of the data we used as input for the below model. The model includes a single stock variable, named Number of Tourists, determined over a period of 30 years, taking the year 2020 as the beginning of the simulation and ending of the simulation by the year 2050. We included in the model specific quantitative input variables, such as tourism carrying capacity, employment factor, emergency level, time until emergency level is reached, revenues per tourist day, fraction of revenues used for marketing, initial number of tourists, initial duration of stay, decline rate without development, decline rate without development These variables are determined as constant variables, based on calculations made with data from National Institute of Statistics, in most cases, but also based on others scientific publications of interest for our Tourism model. Secondly, the model includes auxiliary variables, which are calculated and forecasted with a specific given formula, based on the first mentioned category of variables: initial tourist days, Annual Tourist Days, tourism employment. Also, the model worked with variables and runs interactions determined with the look-up function, following the shape of the graph that experts and stakeholders in the field of tourism think that it should be designed, such as: tourism pressure, tourism attractiveness, impact of marketing on development.

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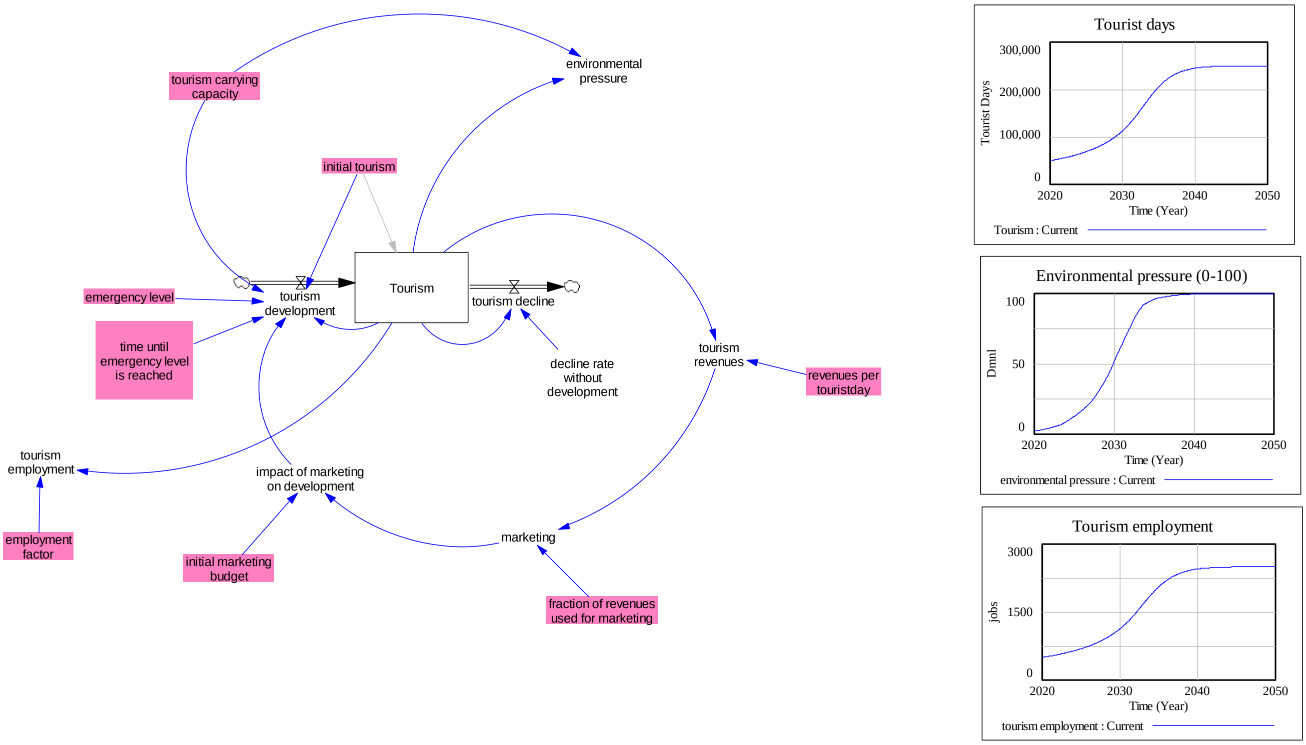

Figure 41 Impact of marketing and reinvested revenues on tourism development

The result from modeling these tourism dynamics is the generic model structure shown in Figure 11. This archetype is a marketing driven model for tourism. This can be used generically and applied in the modeling of impacts of marketing on other economic sectors with reinvestment of revenues used for promoting the sector (for example sea food industry).

3.5.2. Fish farming pressures on environment

One of the *Fish farming* model's feedback structures for the impact of nitrogen load from aquaculture on the water quality takes into account the interaction between the potential aquaculture development correlated with the Fish farming area and the intensification rate of the process (Figure 3.5.2.1).

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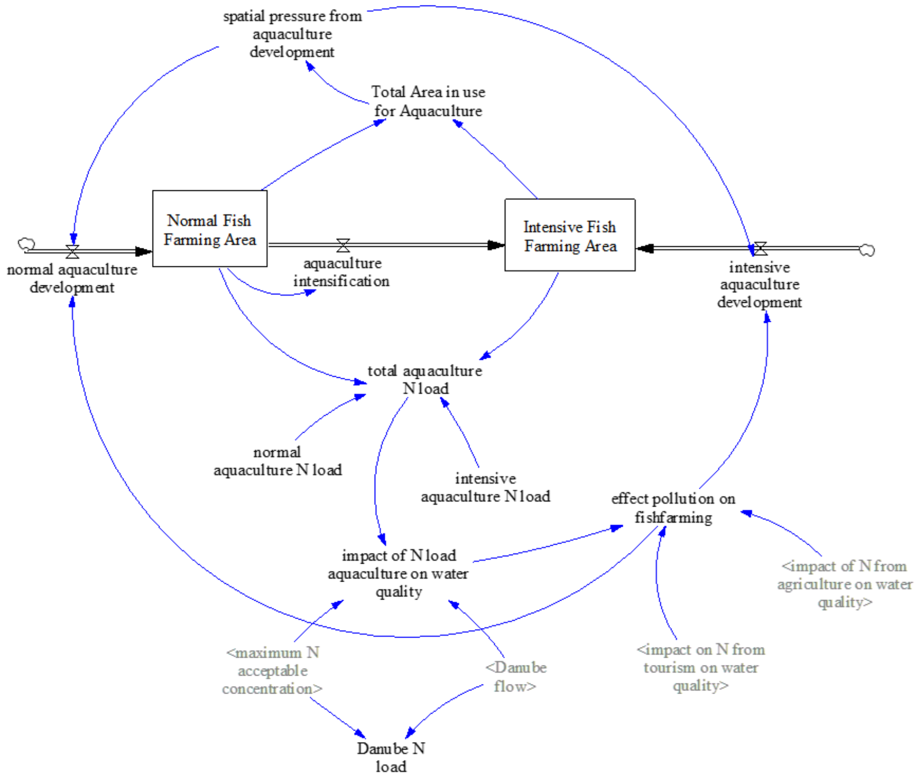
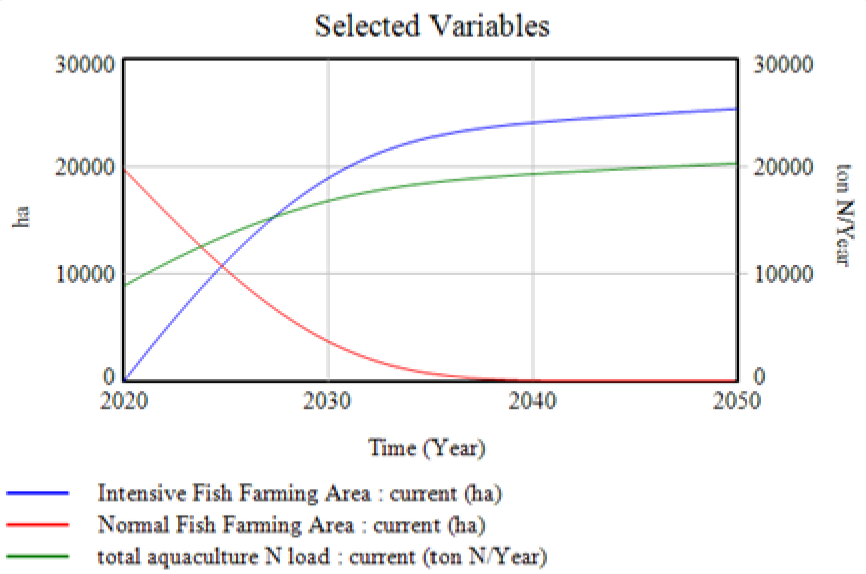


Figure 3.5.2.1. Overview of the generic model related to fish farming pressures on water quality

The impact of nitrogen load from aquaculture is calculated as a grey water footprint type (Hoekstra et al., 2011) by dividing the total nitrogen load from normal and intensive aquaculture to the maximum allowable concentration from Romanian legislation.

As a measure of the intensive fish farming pressure on water quality, we have also used the input from the normal and intensive aquaculture areas and loads. In this generic model construct, the fish farming area is restricted to the maximum available one. The yearly fraction of existing normal aquaculture area which is changed into intensive aquaculture is set to 10%, values to be set being possibly linked with investment and/or technological evolution (Fig.3.5.3.2).



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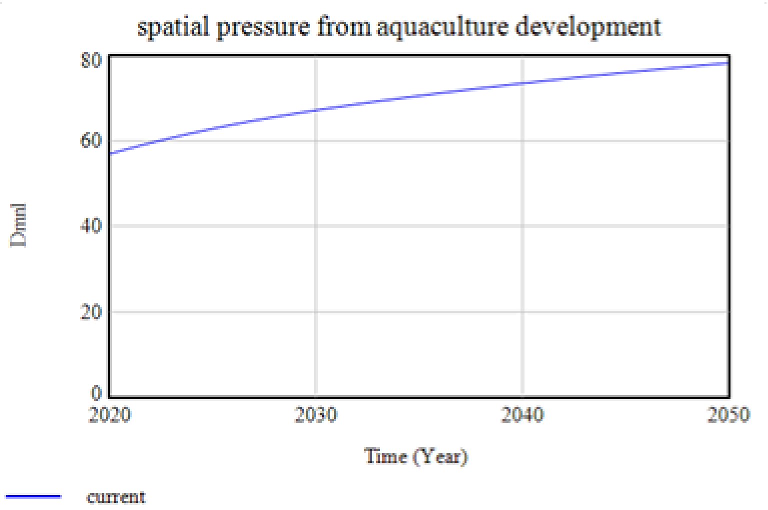

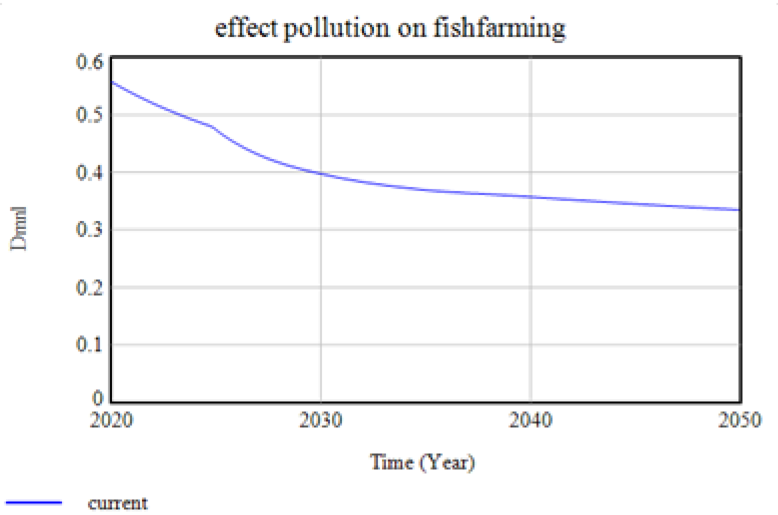

Figure 3.5.3.2. Evolution of the total aquaculture nitrogen loads, spatial pressure and effect of pollution from other sectors on fish farming

3.5.3 Sustainable transitions

The transition towards more sustainable agricultural systems, as targeted in the European Farm to Fork strategy, is modelled in the Romanian Agriculture model. The model is built as a mirrored structure, compiling traditional agriculture and ecological farming. Key isuues were included in the model, such as Economic (farmers' income), environmental (fertiliser - nitrogen use, nitrogen runoff, water supply, and instralation of forest belts), and social (agriculture employment).

The model is designed as a generic crop model, being based on data related to wheat cultivation. However, it can be used for any specific crop of interest, replicating the structure, or replacing the data. The choice of this crop relies on analysis on the largest share of cultivated crops in the Danube Delta region, when speaking of ecological farming

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3.6. MAL06 – Mar Menor

3.6.1. Agricultural pressures on water resources and development of agricultural irrigated land areas

One of the main model constructs with potential for reuse is a feedback structure for the development of irrigated land areas which takes into account the interaction between the observed growth of agriculture and the potential growth rate of agriculture based on water availability (Figure 1).

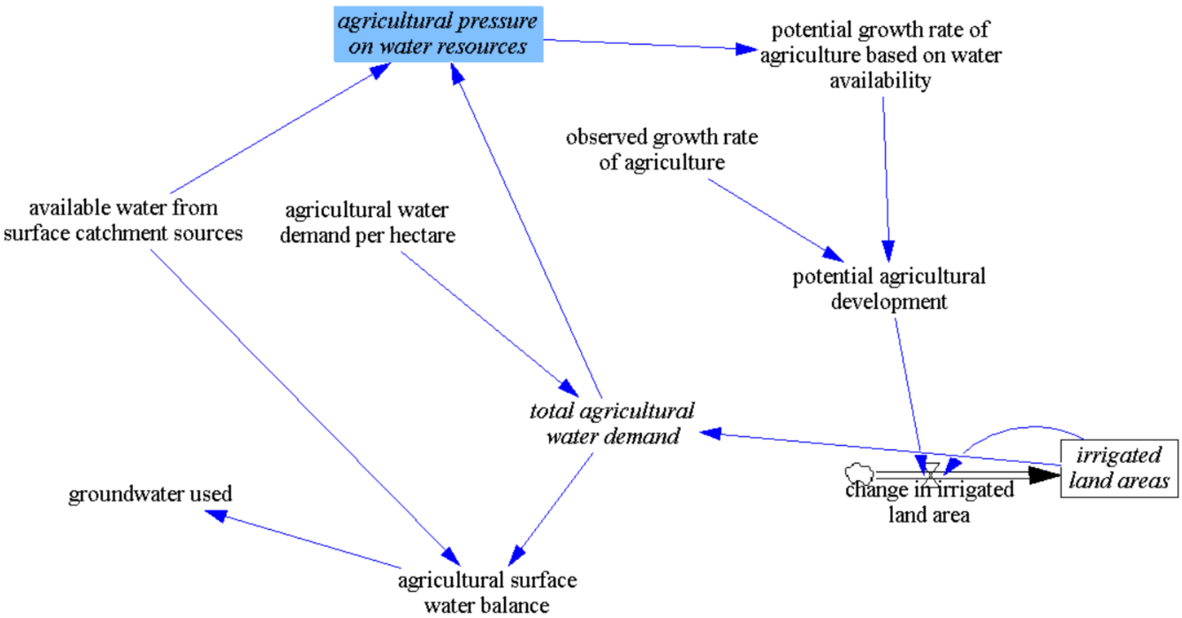

Figure 1. Overview of the generic model construct related to agricultural pressures on water resources and development of irrigated land areas.

The number of irrigated land areas has an associated total water demand based on the water demand per hectare. The total demand must be met by surface and eventually groundwater sources. As a measure of agricultural pressure on water resources, we have used the percentage of the total agricultural water demand not met by surface water sources, which corresponds to non-renewable groundwater sources. This indicator then affects the potential growth rate of agriculture based on water availability, which multiplied by the observed growth of agriculture will result in the potential agricultural development, which in turn affects the change in irrigated land areas. In this generic model construct, groundwater availability is considered unlimited since very often, groundwater balances are too complex and uncertain to include in SD models but the effect of the agricultural pressure on water resources can be clearly seen in the growth curves for the development of agricultural areas and related input variables (Figures 2 and 3). At some point in time when groundwater demand is needed, the change in irrigated land area, which depends on the potential agricultural development and the amount of irrigated land areas, becomes a fixed value and leads to a linear increase in the value of

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irrigated land areas, which otherwise would be exponential (e.g., if available water from surface catchment sources would be unlimited).

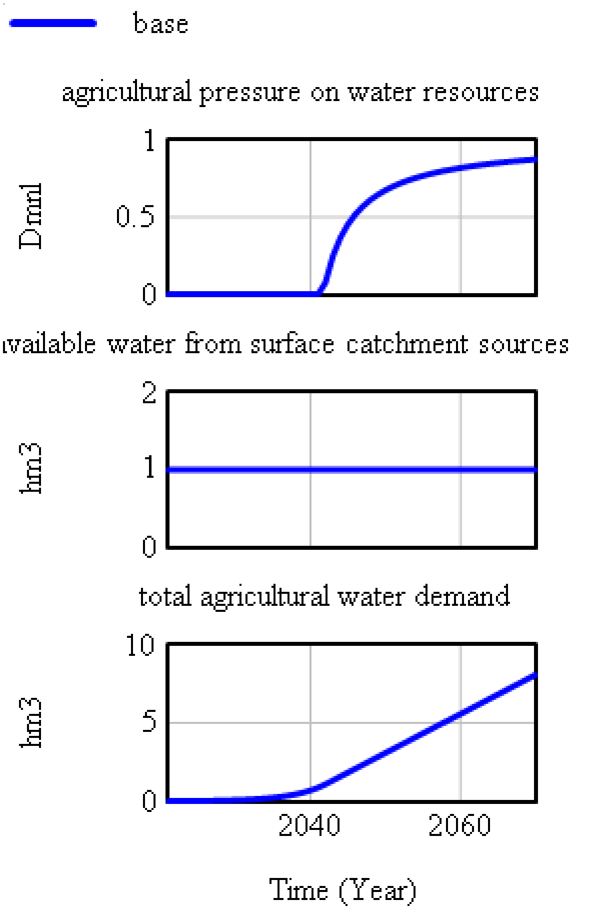

Figure 2. Evolution of the agricultural pressures on water resources over time and its input variables, i.e. available water from surface catchment sources and total agricultural water demand. Demo values were used as input.

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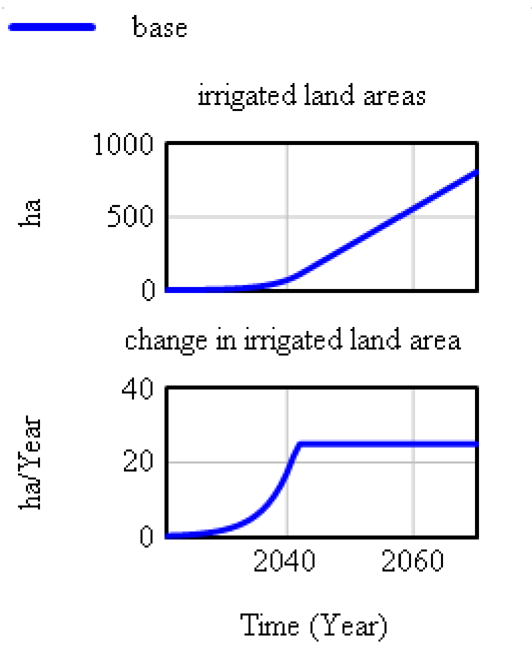

Figure 3. Evolution of the irrigated land areas over time and its input variable, i.e. change in irrigated land area. Demo values were used as input.

3.6.2. Coastal-rural recreation potential

Another generic element is the model construct used to quantify the increase in coastal-rural recreation potential as a function of the promotion of coastal and rural ecotourism activities, as well as of environmental degradation (Figure 3).

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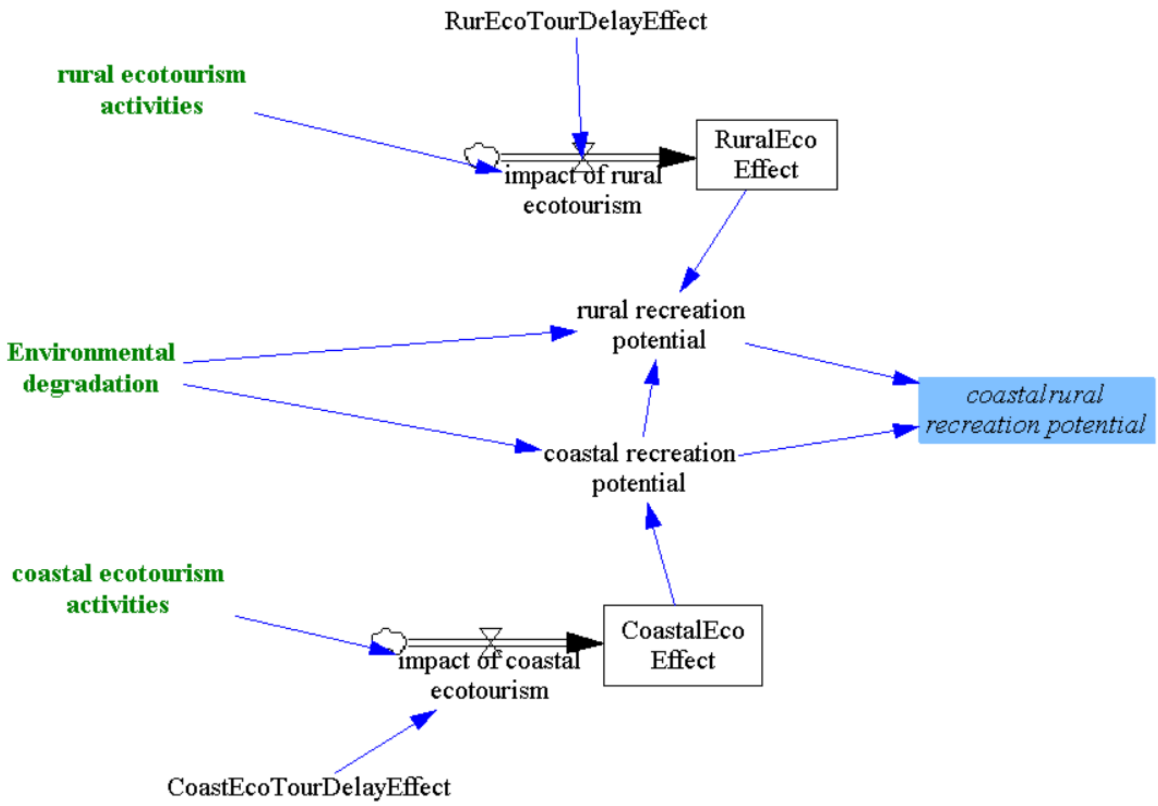

Figure 3. Overview of the generic model construct related to coastal-rural recreation potential.

The promotion of coastal and rural ecotourism activities are relative input variables that range from zero to one, which have a gradual effect on the rural and coastal recreation potential, while these latter variables are also affected by environmental degradation. This gradual impact of the coastal and rural ecotourism activities is represented by the coastal and rural EcoEffect variables. On the other hand, the rural recreation potential is indirectly affected by the coastal recreation potential since in most situations coastal tourism precedes rural tourism and a flow of tourists from coastal to rural areas is observed. Finally, the coastal-rural recreation potential is the average of both of them. The model allows to study the effect of the drivers individually and in combination and assess their importance (Figure 4).

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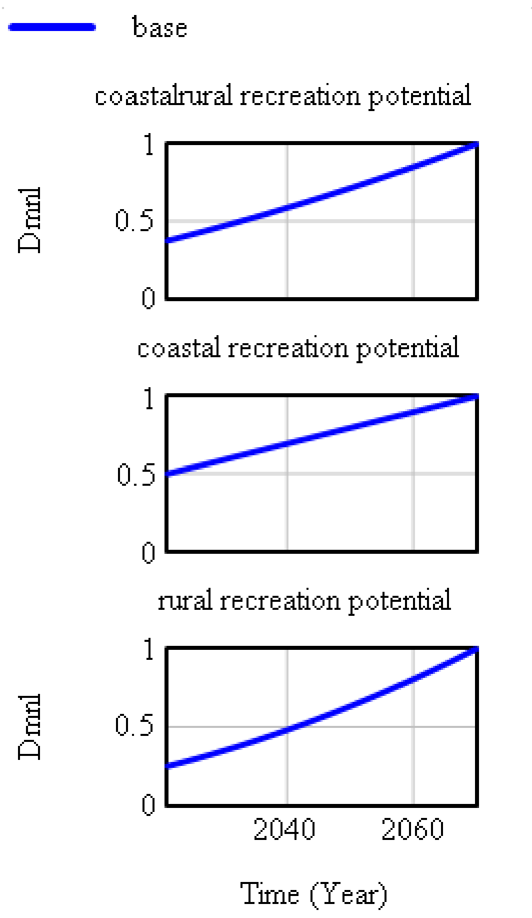

Figure 4. Evolution of the coastal-rural recreation potential over time and its input variables, i.e. coastal and rural recreation potential, under a scenario based on a full implementation of coastal and rural ecotourism activities and no environmental degradation. Demo values were used as input.

3.6.3. Environmental education and territorial bonding

Another generic element is the model construct used to quantify the increase in territorial bonding as a function of the promotion of environmental education activities (Figure 5).

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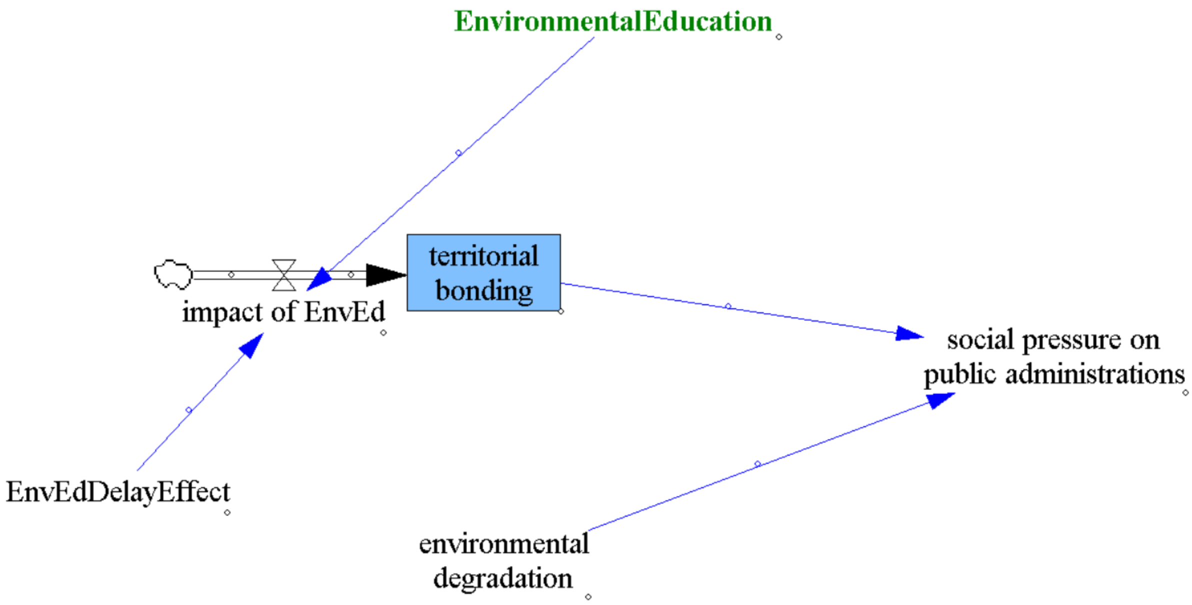

Figure 5. Overview of the generic model construct related to environmental education and territorial bonding.

The promotion of environmental education activities is a relative input variable that ranges from zero to one, which has a gradual effect on the territorial bonding. On the other hand, territorial bonding and environmental degradation increase social pressure on public administrations. While the effect of environmental education on territorial bonding is gradual, environmental degradation could be a steady value or change over time in the form of events that could potentially trigger a social response (Figure 6).

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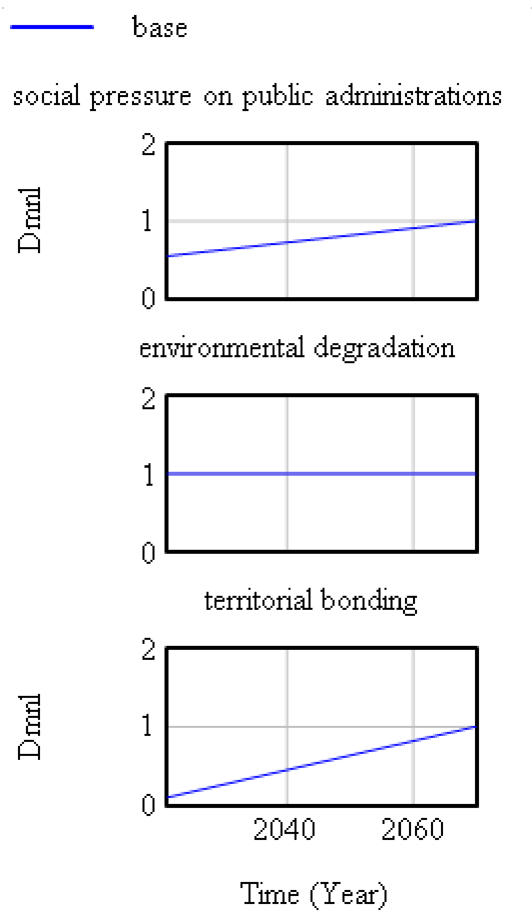

Figure 6. Evolution of the social pressure on public administrations over time and its input variables, i.e. environmental degradation and territorial bonding, under a scenario based on a full implementation of environmental education activities and severe environmental degradation. Demo values were used as input.

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4. DISCUSSION

Depending on the level of complexity and scope of the models, direct reuse for a different context or region is generally not feasible without significant modification. However, generic and reusable model constructs or system archetypes could be derived from or were already used in the models. Thematically, the models cover topics ranging from renewable energy, tourism and aquaculture to land management and agriculture. Nevertheless, the general focus of the models is on agriculture and (coastal) water quality. Policy and business indicators related to or relevant for employment, food production, and the EU Green Deal are included in most of the models. Due to the differences in model scope (themes and delineation of the model), model detail, granularity (balance in detail) and the number of sub models, the MAL models are not yet interoperable at this stage, despite the modelling guidelines and examples provided. However, model constructs used and technical solutions for problems have an added, generic value surpassing their use in the MAL models. In several cases, the MALs already reused model constructs to expand or adjust their model design. For example, the Greek and Romanian MAL use a similar stock-flow structure for modelling the impact of agriculture transition on water quality, food production and employment.

An integrated strategy for post-project exploitation of the project Key Exploitable Results (KERs); including the generic model constructs, has been outlined in WP6 Deliverable D22. This document also presents different options for IPR management. **The mid- and long-term exploitation** of the outcomes of COASTAL are expected to contribute significantly to the coastal-rural synergy, improving the quality of EU coastal waters, increasing job potential and fostering regional development of coastal and rural areas due to the expertise developed and exchange. Practically, the project results will be used and exploited in the longer-term via the international network of the Multi-Actor Labs in the COASTAL Knowledge Exchange Platform or KEP[5]. The **post-project maintenance and expansion** of the COASTAL tools and services will be organised by a post-project collaboration agreement between the main research partners, aimed at maintaining, further developing and exploiting the project outcomes and thematic and methodological expertise to the extent possible. It will put in place a consortium of research institutes that will support regional, national and EU level policy makers for future coastal and rural planning, with a special focus on environmental impacts of economic activities. Free access will be provided to the generic COASTAL tools and demonstration cases to raise the interest of new clients and target groups (see Figure 42) and establish new collaboration with the academic community interested in systemic approaches for coastal-rural development and long-term planning involving participatory aspects.

[5] www.coastal-xchange.eu

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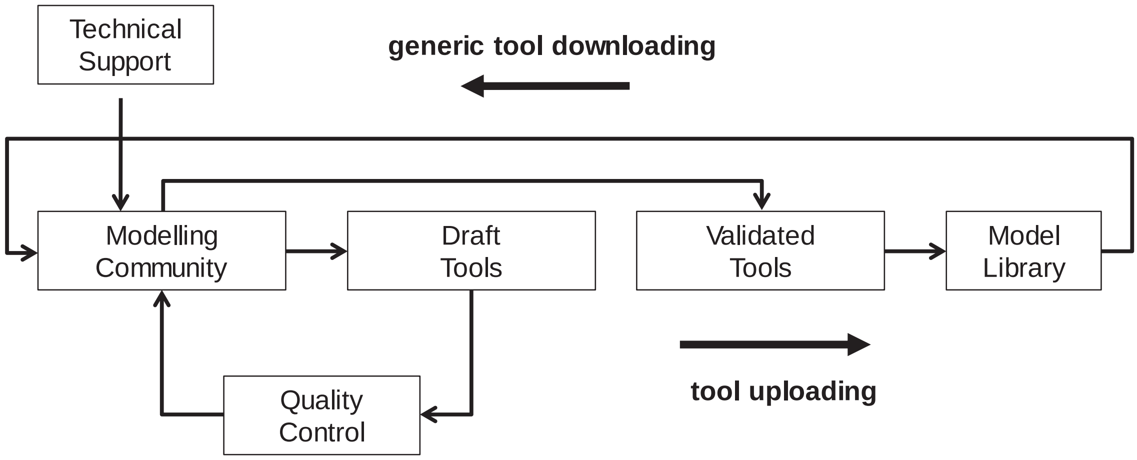

Figure 42 Life cycle for a generic model library (after De Kok et al., 2015).

The services provided by and with the platform can be divided into: (1) training of target group representatives in the application and interpretation of the COASTAL models and toolbox; (2) focused and updated business and policy analyses using the COASTAL models, and (3) technical support with the adaptation and expansion of existing models. Not all parts of the project outcomes may be sustainable, and it is important to consider the dissemination and exploitation as a progressive, iterative process, extending beyond the duration of the project. The uptake and practical implementation of innovative solutions and strategies will depend on long-term investments, and require adjustments under changing environmental, institutional, and economic conditions.

The general recommendation to the MAL modellers to design and implement their models step-by-step, keeping models balanced in terms of the level of detail, and allowing for complexity in the feedback structure of the complete system rather than processes and sub-models was not always followed. Users tended to focus on details and pursue a bottom up development process. As a result generic, reusable model structures were more difficult to identify for some of the MALs. The objective of a generic model library is closely related to the guidelines provided for SD modelling. Considerable effort was spent on hands-on support for assisting the MALs with the design, implementation and testing of their models. Addressing case-and model-specific problems sometimes required resources that could have been spent on developing plug-and-play model structures in an early phase of the modelling process and would have created a better starting point. All in all it is clear that each MAL followed a different trajectory to develop their models with the room given to translate the outcomes of the stakeholder engagements into quantified models. In principle, this is good but more strict guidelines to a support a step-by-step design process would have increased the efficiency of the modelling, interaction between the MALs and reusability of the set of models developed in COASTAL. In line with this further improvement and development of new model constructs should preferably be based on reuse of existing generic model constructs and not on further ad-hoc expansion and detailing of the structures that are currently deployed in the models for eth MALs.

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