COASTAL
Collaborative Land-Sea Integration Platform

Deliverable D08
Model Validity – Final

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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

WFD – Water Framework Directive

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1. INTRODUCTION

1.1. The purpose of System Dynamics modelling

In this document models are understood to be numerical, narrative or mental frameworks which can help us understand and analyze complex socio-environmental systems and support policy analysis. Validation of models is to ensure the model developers and users of the model obtain **confidence** in the ability of the model to simulate the real system. Any model is an abstraction of the reality but the response of the model outcomes to changes in the model input and parameter settings should be correct within certain limitations to make the model useful for policy applications. This validation is directly linked to the purpose of the model: without a proper understanding of a model's purpose any testing of the model will be useless (Forrester and Senge, 1980) as the wrong questions will be asked. This brings us to the question why any quantitative modelling is needed in the first place (Sterman, 2000). While causal loop diagrams (Tiller et al. 2021b) and narrative scenarios, for example, are useful for conceptual analysis of problems and solutions, quantitative models allow us to analyze the impact of alternative actions under different conditions, serving as a laboratory for policy analysis. Although the human brain is capable of providing part of the answer this becomes more difficult when multiple factors interact, time delays and non-linearities are at play, and extrapolation of historic patterns becomes inadequate. This is certainly true for complex, dynamic social-environmental systems which are intensively used and rapidly developing, with economic activities competing for resources such as space, water, energy and skilled labour.

System Dynamics (Sterman, 2000) or System Dynamics (SD) modelling was selected as modelling framework based on the graphical transparency of this type of modelling, the direct translation of problems into model structures, consideration of systemic limitations, appropriateness for including human and social aspects directly in the models, and the limited computational requirements – making SD models particularly useful for interactive development and use by and with stakeholders. System Dynamics modelling is based on explaining the dynamic behavior of systems from the underlying **feedback structure** of interacting 'stock' and 'flow' variables. Problems can be understood and innovative solutions developed with this particular type of model by making changes in these feedback structures rather than the parameter settings of the models. The technique of SD modelling was introduced in the 1960s by Jay Forrester (Forrester, 1968) and since then used for a wide range of applications ranging from urban policy, logistics, control management, engineering and financial management to environmental management. The most well known SD model of which the validity is still being debated today is the World03 model (Forrester, 1971) describing the exploitation of resources at a global scale. A general consensus will never be reached although retrospective analysis (Featherston and Doolan, 2012) can help understand the nature of the criticism.

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By nature, stock-flow modelling is strongly problem-driven and an SD-based modelling approach is used to avoid modelling the system as such, if this can be avoided (Sterman, 2000). Clients or stakeholders interact with modellers to create mental models or 'mind maps' first clarifying the problem at hand and defining the way the problem(s) are connected to specific policy or management indicators and potential solutions (Tiller et al., 2021a; De Kok et al., 2020). The design, implementation and validation of SD models can be challenging, particularly when stakeholder engagements result in overly complex or ill-balanced causal loop diagrams or modellers are less familiar with SD modelling. The real challenges faced are: (1) to properly align qualitative and quantitative methods not developed with this integration in mind (2) to ensure coordination with existing and planned development strategies, and (3) to engage stakeholders directly throughout all phases of the project. Ideally, stakeholders, actor and modellers interact continuously and directly to address these challenges and design, implement and test SD models for the prioritized issues identified in the causal loop diagrams. The COASTAL models (Viaene et al., 2021) capture the essential dynamics of the land-sea systems and can generate **counter-intuitive response** to alternative policy and business decisions. Stress testing these decisions with the models generates new information which can be used to design, fine tune or adjust business road maps and policy recommendations.

1.2. Building confidence in SD models

The purpose, usefulness and confidence in SD models are strongly interconnected. Rather than scientific validation the testing of SD models is aimed at establishing a sufficient (not maximal) level of confidence in their usefullness given the purpose of the models and perspective taken (Senge and Forrester, 1980). For COASTAL the general purpose is to develop **evidence-based policy analysis** aimed at land-sea synergy. Standard numerical and statistical techniques for scientific model validation are less adequate for testing SD models. Instead testing of SD models should focus on establishing a sufficient degree (given the purpose) of confidence in the structure of the model, the dynamics generated by the structure, and the policy implications of the model dynamics. A wide range of tests is available for this purpose (Forrester & Senge, 1980), some of which are more useful than others. In the context of COASTAL testing of the models was more pragmatic and took place along three lines:

1. Co-creation of models and establishing confidence in the model feedback structure together with stakeholders;
2. Testing of the model dynamics in response to changes in the model structure, parameter settings and exogeneous model input (scenarios) by the model developers;
3. Testing of the policy implications of the model and confrontation of stakeholders , potential users and experts with policy analysis

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Qualitatively, well designed SD models are less sensitive to changes in the parameter settings as the feedback structure governs the dynamics. This property of SD models is extremely important, both for testing and application of SD models (Senge and Forrester, 1980; Sterman, 2000). A generalized overview of the **iterative** SD modelling process was provided in 2010 (Figure 1) and the role of structural validation elaborated for the example of energy policy (Qudrat-Ullah and Seaong, 2010). An important distinction was made by the authors between simulation models with an operational and policy oriented purpose. **Policy models**, including SD models, are developed to explore future scenarios and management policies rather than fine tuning the operation of systems which can be validated against real-world data.

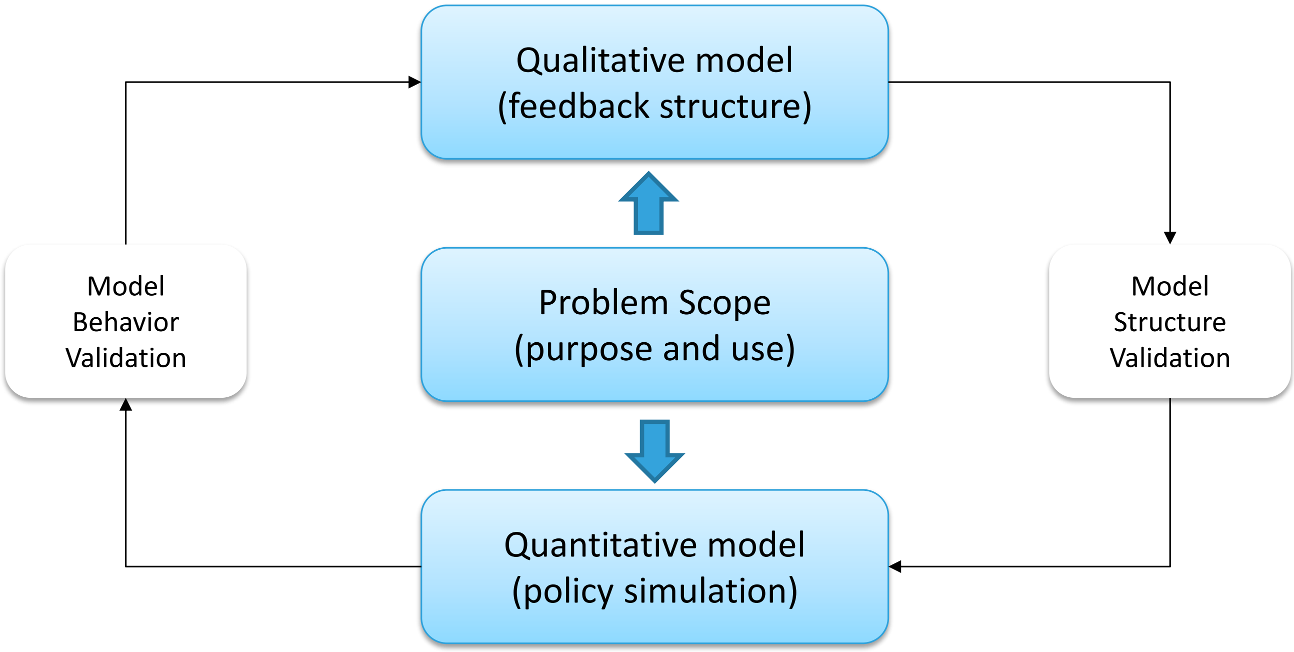

Figure 1 Generalized overview of the SD modelling process (Qudrat-Ullah and Seong, 2010).

The quality of the models can be improved gradually by engaging the stakeholders and actor partners in the process of model confidence building (Senge and Forrester, 1980), obtaining feedback on the model scope (boundaries and level of detail), model structure (land-sea interactions included in the model), the model dynamics (time-dependent patterns generated with the models) and the policy implications and relevance for decision making.

As explained, a proper understanding of the **model purpose** is of critical importance for the design and successful application of SD models (Sterman, 2000; Hovmand, 2014). A number of questions need to be

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answered in what is usually referred to as the 'problem scope'. Misunderstandings of the problem scope will lead to models which lack focus, are not solving the problems or answering the questions of the intended users, and inefficient modelling projects. A common mistake is for modellers attempting to model the system as a whole rather than the problems generated by its dynamics (Sterman, 2000). In addition, the model should not be a complete representation of the system in all its detail, but a simplification of reality. Realizing this helps defining the proper **model boundaries**, both in scope and level detail. Another common misunderstanding is that data are always quantitative. Qualitative data, mental models and other forms of non-quantitative knowledge are equally useful for designing a stock-flow model.

The following steps outline the **general modelling strategy** followed in COASTAL :

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

In practice, models were developed and tested with multiple iterations between these steps. Defining the problem scope, i.e. the purpose of the model and what is to be included or not, is of key importance and a number of questions were formulated (De Kok et al., 2020). We summarize the most relevant questions in terms of SD model testing:

a) **Problem definition**: which problem(s) are to be addressed with the model and why? If multiple problems occur, can these be prioritized or should separate models be developed? The model design depends on this problem definition.
b) Related to the previous question and model purpose: who is the **problem owner** perceiving the existing or future situation as a problem, or who is affected by the problem and who or what is causing the problem?
c) Depending on the complexity, dynamics, need for quantified modelling and other factors modellers should always ask themselves if a quantified stock-flow model is the appropriate tool for understanding and analysing a problem. Stock-flow modelling can be used in COASTAL to make solutions **evidence-based**. Modelling may not be needed to develop solutions, or alternative

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

d) **Model purpose** is equally important and highly relevant for the design of an SD model. The purpose of the model can range from problem solving to introducing SD techniques, demonstration and educational training for awareness raising. It's important to emphasize that SD models are technical instruments, generally not appropriate for interaction with persons not familiar with, or, not interested in models as such. This is even true for well-polished SD models.

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

Model purpose is of key importance for the design and validation of any model. In the context of this deliverable it is useful to make a distinction between research- and policy oriented models Table 1.

Research models	**Policy models**
time horizon, temporal and spatial resolution are *process* centred	time horizon, temporal and spatial resolution are *policy problem* centred
accurate representation of processes	*adequate* representation of processes
modelling propels data collection	*data constrain* model development
in depth and sectorial	*sketchy but integral*
as complicated as necessary	*as simple as possible*
scientifically *innovative*	scientifically *proven*
raises more *questions* than answers	build to provide *'definite' answers*
interesting and worthwhile *in their own right*	interesting and worthwhile only *through their output*
numbers can be validated	*outcomes* can be validated

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response time, interactive-use *not critical*	response time, interactive-use *critical*
transparency and user-friendliness are *superfluous*	transparency and user-friendliness *essential*
the developer is the user	end-user involvement during development is critical

Table 1 Research versus policy modelling (Engelen, 2002).

By definition, SD models are policy-oriented tools with a strong problem-driven design. This should also be taken into consideration in the testing of this particular type of model, provided it has been developed with the right purpose in mind. The level of detail, handling of data, time resolution and complexity will be different from typical research models with more priority given to the presentation and interpretation of policy outcomes. If tools exist for operational decision making it may be wrong to design an SD model replacing such tools. Trying to do this can be counter-productive and raise questions from experts as expectations with respect to the level of detail, data quality and numerical testing are not met. Nevertheless, these instruments can be complementary. For example, a hydrological model can tell us on what day canal intake of water will be necessary to address water shortage for a specific type of agricultural crop while a complementary SD model could use a function for the yearly number of times canal intake is necessary, allowing application to time scales of decades or longer.

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2. METHODOLOGY

2.1. Tests for building confidence in SD models

Following Forrester and Senge (1980) we classify the validation of SD models in tests addressing model structure, model behavior and policy implications (Figure 2) as part of the modelling workflow.

- **Model Structure**: addresses the validity of the model structure in representing the structure of the real system at the appropriate level of detail, given the model purpose;
- **Model Behavior**: addresses the validity of the dynamics generated by the model;
- **Policy Testing**: addresses the usefulness of the model as a policy analysis tool and is aimed at creating confidence in the policy implications

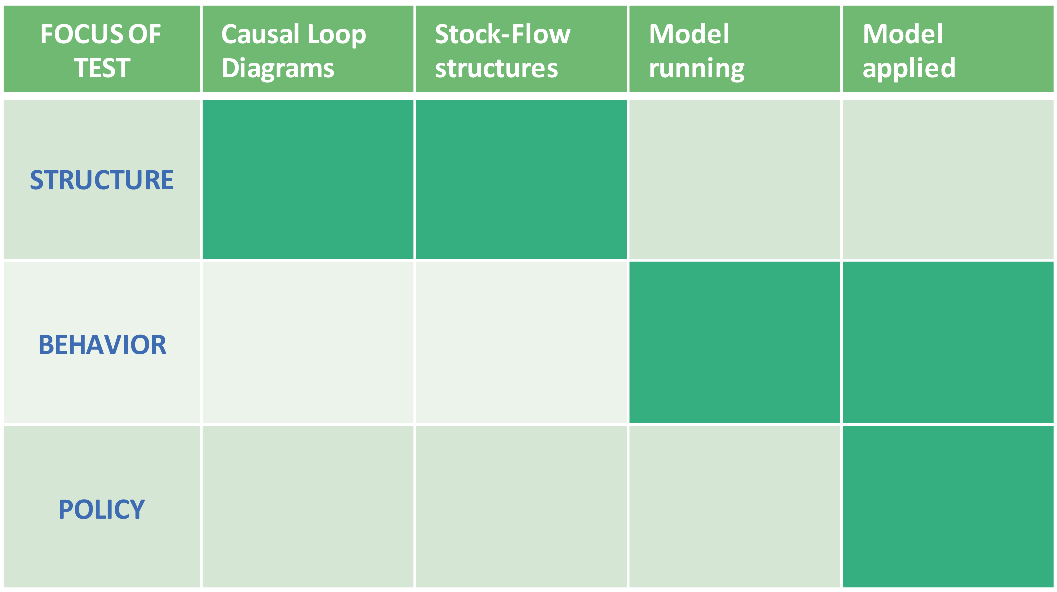

Figure 2 Focus of the confidence building process as related to the progress made in the policy modelling cycle.

This type of testing addresses the model feedback structure without examining the impact structure has on the behavior of the model. The different tests proposed in the literature (Forrester and Senge, 1980; Sterman, 2000) are summarized in Table 2.

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Table 2 Different tests with purpose and methods for building confidence in SD models, adapted and condensed after (Forrester and Senge, 1980) and (Sterman, 2000).

Type of test	Purpose/questions	Approaches and tools						
		Expert judgment	Conceptual modelling	Restructured modelling	Data, numerical methods	Behavior testing	Impact assessment	Other
Boundary adequacy (scope and detail)	• Relevant model structure included • Appropriate level of detail • Model behavior insensitive to change in boundaries • Policy recommendations insensitive to change in boundaries							
Structural validity	• Consistency with knowledge on structure of real system • Appropriate level of aggregation • Abidance with physical laws							
Parameter validity	• Consistency with descriptive knowledge and numerical data • Real system meaning of parameter • Constant value for given time horizon (i.e. not a variable)							
Extreme conditions	• Validity of equations for extreme input • Plausible response of model to extreme input							
Behavior validity	• Qualitative correctness • Quantitative correctness • Behavior replicates problem symptoms endogenously • Relevance and existence in real system of behavior modes							

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Dimensional testing	• Consistency of units in equations, variables and parameters							
Behavior anomalies	• Model does not generate anomalies with changed assumptions or settings							
Sensitivity analysis	• Model does not generate implausible behavior for parameter changes within their uncertainty range • Policy recommendations not affected by parameter uncertainty							
Surprise behavior	• Ability to generate counterintuitive or unobserved behavior • Correct response to new conditions							
System improvement	• Ability to contribute to improvement of the real system							
Numerical accuracy	• Time step and integration method do not affect model behavior							

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2.2. Testing the COASTAL SD models

2.2.1. General strategy for testing the COASTAL models

Application of all the tests for confidence building to the COASTAL models was considered less appropriate and not feasible given the scope and priorities of the project. In addition, the model validation can be based on a selection of the tests (Forrester and Senge, 1980). The main purpose of this validation was to develop confidence on the model structure and behavior among the model developers and intended target groups. Much of this testing was carried out implicitly by the model developers during the design and improvement of the models. To support the process a more pragmatic approach was adopted based on tutorial examples of problems, modelling workshops, online sessions to address problems as well as practical guidelines. These were centered on the following aspects of model validity:

a) All models should run without errors or behavior anomalies which cannot be explained or are highly improbable in the real system;
b) All models should be dimensionally consistent in terms of the units used in equations (tested by means of the in-built VenSim tool for unit verification[1]);
c) The model structure and model behavior should be verified with experts and other modellers, preferably initially not involved in the model design;
d) The policy implications generated by the model should be properly interpreted and be clarified to the stakeholders and target groups
e) Testing of the **policy sensitivity** of key indicators against the impacts of uncertainty in the input conditions (scenarios). The outcomes of this type of analysis are relevant for Task 5.4 (robustness analysis) as it allows to weigh the impact of scenario uncertainty on policy indicators against their sensitivity for the policy interventions.

2.2.2. Sensitivity analysis

A distinction should be made between three types of sensitivity of SD models: numerical (or parametric), behavior mode and policy sensitivity(Sterman, 2000). Numerical sensitivity is present in all SD models and can be observed when changes are made in the model structure, equations (quantification of interactions) and parameter settings. This will affect the numerical outcomes of the models. Behavior mode sensitivity of SD models is fundamentally more interesting and can be observed when changes to the model assumptions or structure that affect the dynamic pattern of a model, for

[1] https://vensim.com/docs/

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example from S-shaped growth to overshoot-and-collapse behavior (see Table 1, deliverable D12). Policy sensitivity is observed when changes in the assumptions affect the policy implications of the model. The three types of sensitivity are often misunderstood or mixed up by SD modellers who tend to interpret numerical sensitivity of classical models as policy sensitivity. Again, the type of sensitivity analysis will depend on the purpose of the model. Taking the example of environmental degradation represented with an SD model feedback structure generating overshoot-and-collapse behavior: it may be less interesting when this collapse occurs (numerical sensitivity) than to avoid a collapse of the system altogether by intervening in the model structure – i.e. developing policy recommendations based on understanding of this feedback structure.

Parametric sensitivity analysis implies first estimating the uncertainty range of the parameters considered to be both highly influential on the model behavior and uncertain (Sterman, 2000) and then assessing the impact of this uncertainty on selected key policy indicators. Here an obvious choice is to focus this analysis on parameters representing the uncertain conditions driving the model – i.e. related to the scenarios for climate change, socio-economic development etc. Even for models of moderate complexity this type of analysis can take considerable time if all combinations of parameters have to be analysed (multi-variate analysis). To facilitate the analysis and explore the sensitivity efficiently a distinction can be made between "worst" and "best" case estimates of parameters (Sterman, 2000). Furthermore, most SD modelling software, including VenSim comes with built-in tools for automatic sensitivity analysis based on Monte Carlo simulations. This implies models are run a sufficiently large number of times with input parameter settings drawn from probability distributions. The outcomes can be shown as confidence bounds for selected variables or indicators (Figure 3).

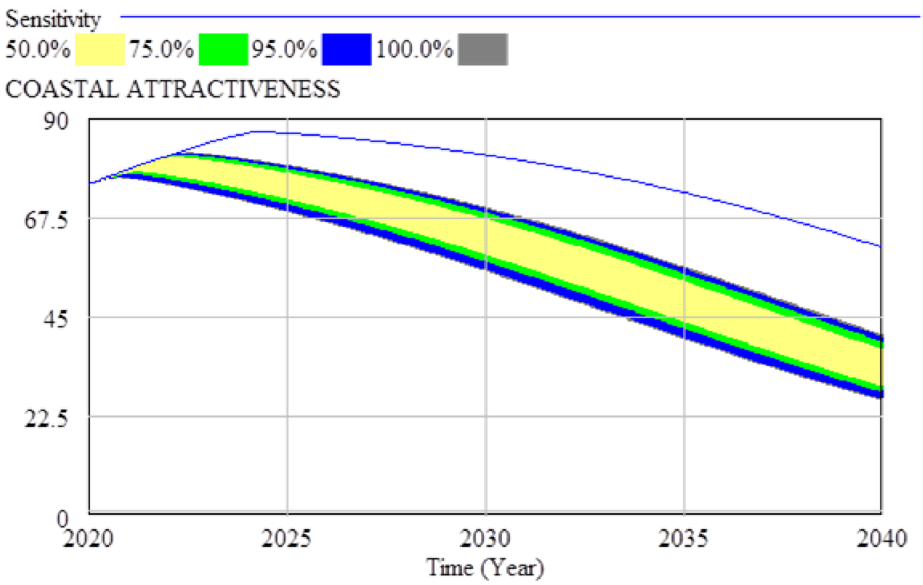

Figure 3 Example of confidence bounds for a tourism development model, using the Monte Carlo tool in VenSim.

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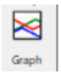
The following different technical options are available in VenSim for sensitivity testing and were considered for COASTAL in ascending order of effort and expertise required:

a) Running the model with different parameter settings for the model input. The impact of the parametric uncertainty on a variable or indicator of choice can be examined using the in-built VenSim graph tool: 

. As an example we take the tourism submodel for the Romanian Multi-Actor Lab (Figure 4) and examine the parameter sensitivity for the average duration of overnight stays (measured in days per visit).

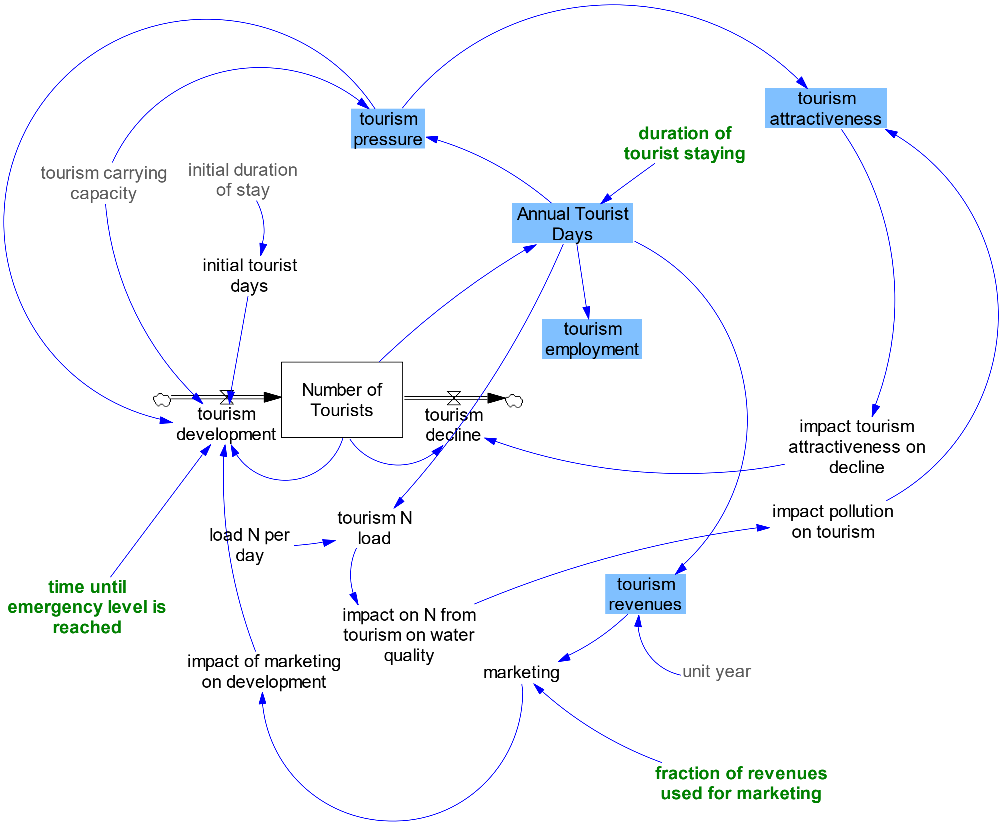


Figure 4 Tourism submodel for the Romanian Multi-Actor Lab.

Next, we run the model with the shortest duration of stay of only 1 night, and again a presumed absolute maximum of, say, 10 days. The long-term impact on the annual number of tourists visiting the area and related pressure (measured relative to the carrying capacity) is shown in Figure 5. The influence of this parameter on the behavior of the system is clear and raises several questions in terms of the model behavior and policy implications of the test. For example, what would happen if tourists inflow approaches the maximum limit (hotel capacity etc.)?

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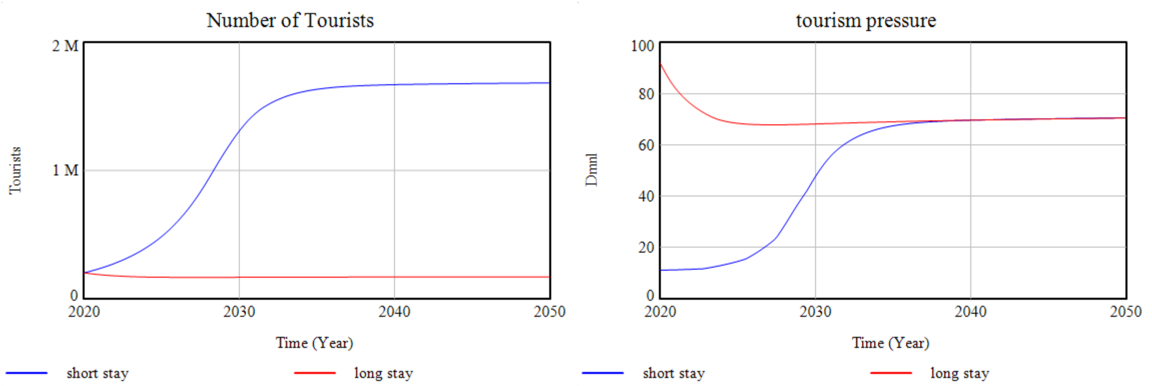

Figure 5 Impact of average duration of stay on number of tourists and tourism pressure, a dimensional index in the range 0-100.

b) Identical approach as a), except for the use of the VenSim tool for exporting model simulations to external files, generally a spreadsheet, allowing further processing and graphical visualization. This is not difficult and can be used to improve the presentation of results.

c) Instead of using the graph tool of option a) one can set up custom-designed graphs with more flexibility to redefine titles, set axis ranges, line properties etc. This functionality is a bit more time consuming, depending on the number of variables to show. It has been used by the partners to add a policy dashboard with model settings and key indicators to their model.

d) Application of the VenSim Monte Carlo tool. After identifying the uncertain parameters, setting the uncertainty range and type of probability distribution the modellers can select the indicators to show. This procedure works through a number of steps which are as follows:

First we open the sensitivity tool:

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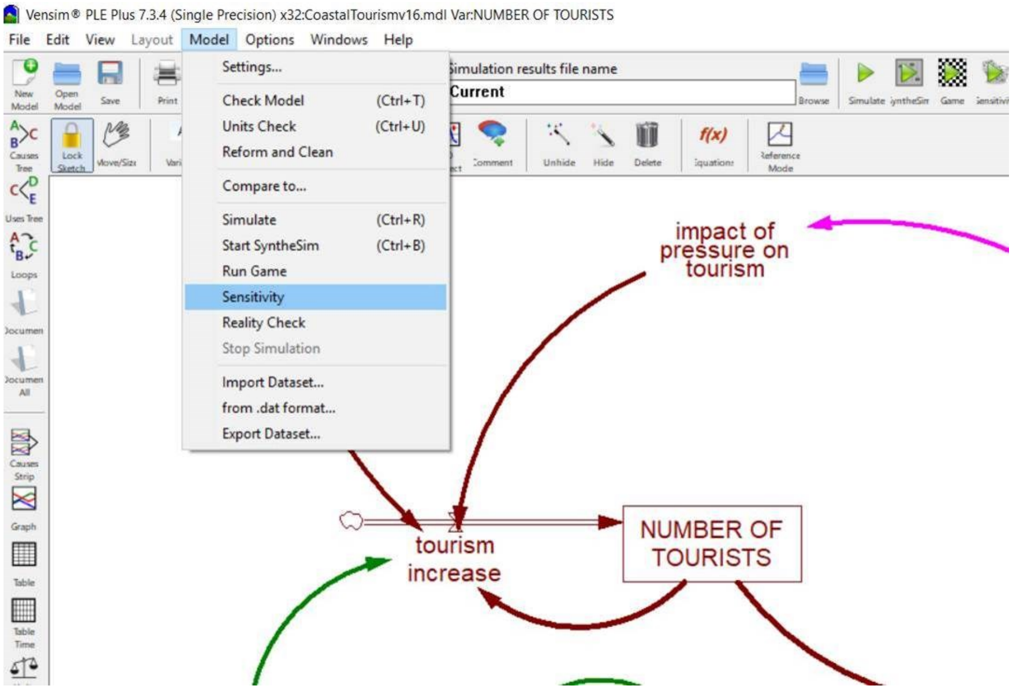
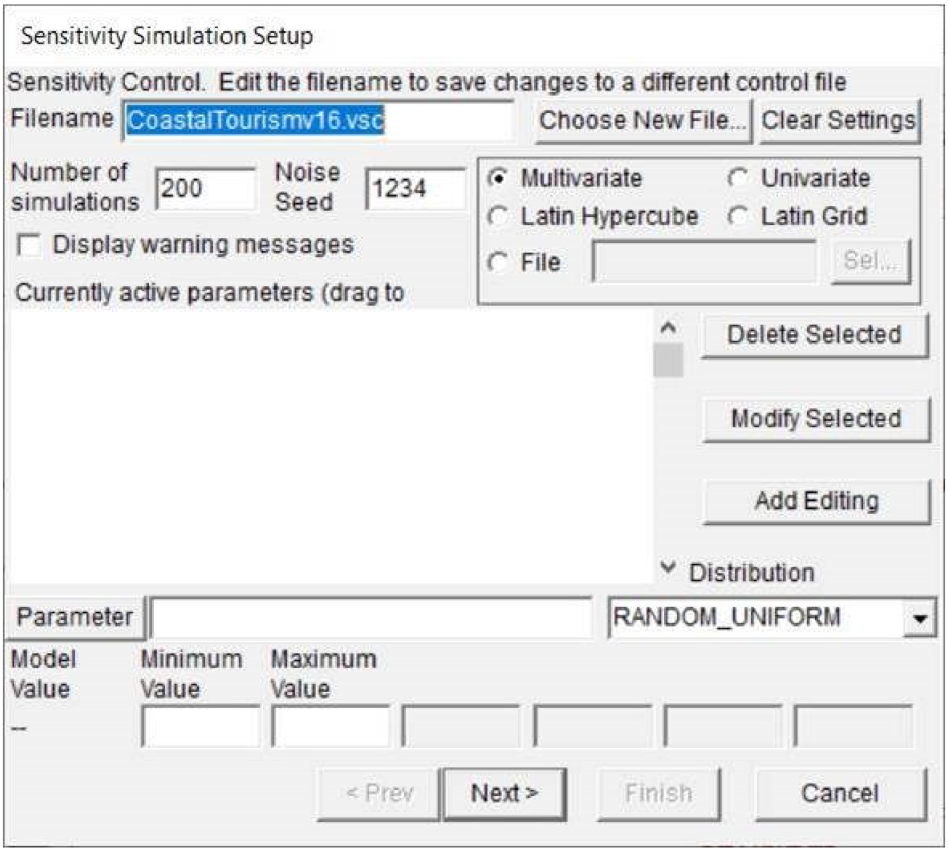


e)

This opens the following dialogue:



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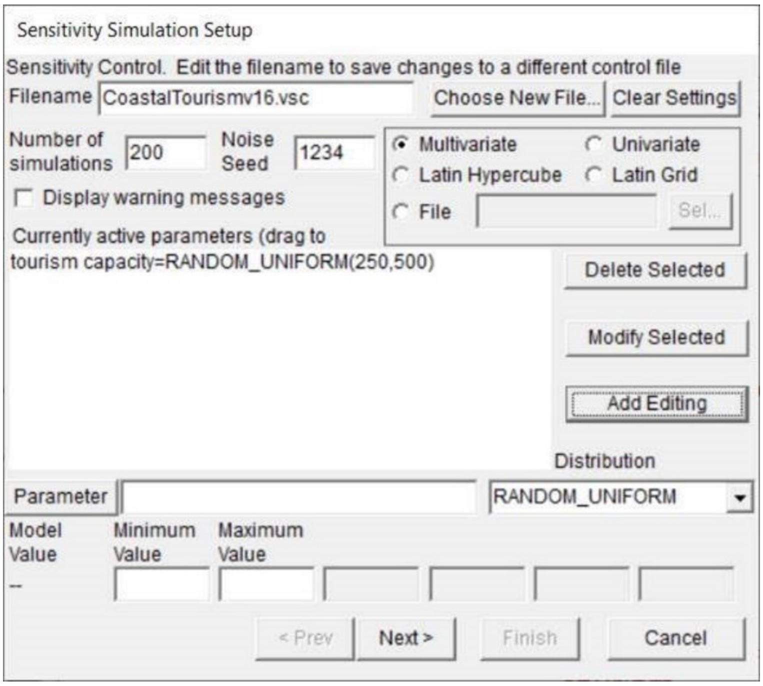
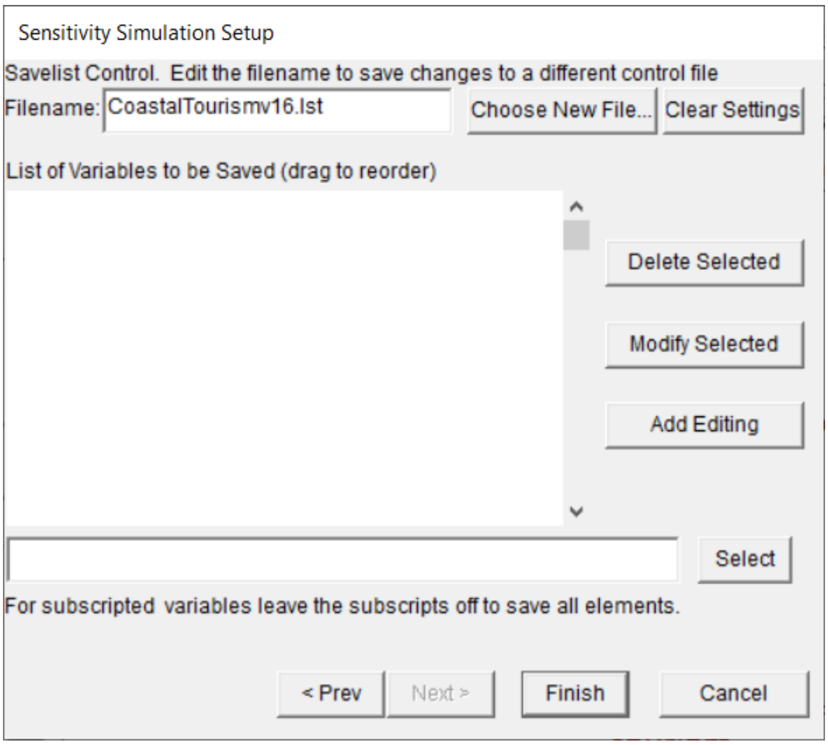
The sensitivity tool can be set for a specific number of simulations, usually in the range 100-200, with a "noise seed" 1234. Click on the button "Parameter" and select the parameter you want to vary: "Tourism Capacity". Then set the range between 250 and 2500. Finally, click on "Add Editing". This should give the following result:



Multiple variables can be varied simultaneously for a multivariate analysis. Now click on "Next >", this should give:



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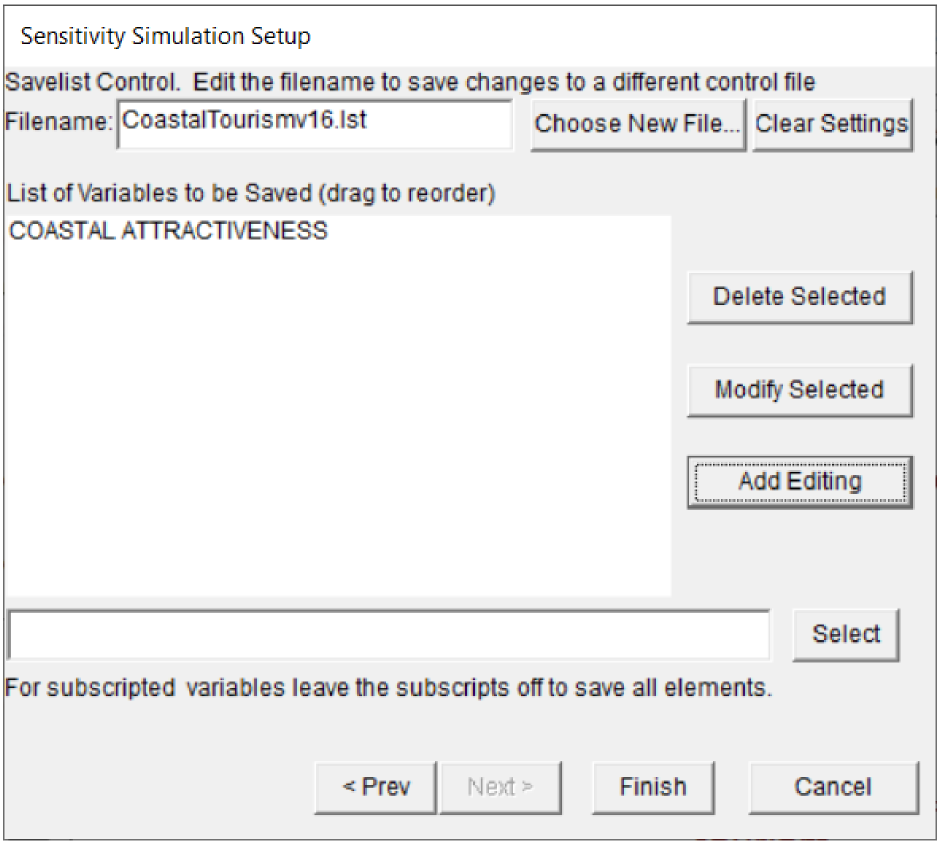
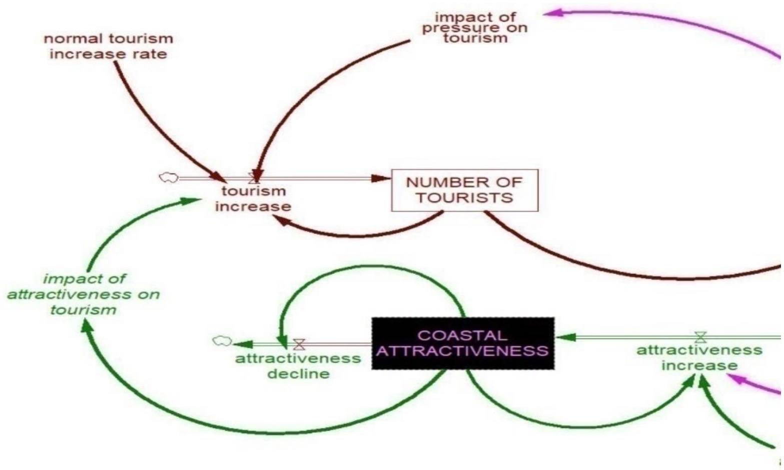
Click on the button "Select", and select the variable for which you want to examine the sensitivity, in our case "Coastal Attractiveness". Then click on "Add Editing" once more, which gives the result:



Now click on "Finish", which will make VenSim run 200 simulations (in a second). Now highlight "Coastal Attractiveness" by left-clicking the mouse on this variable:



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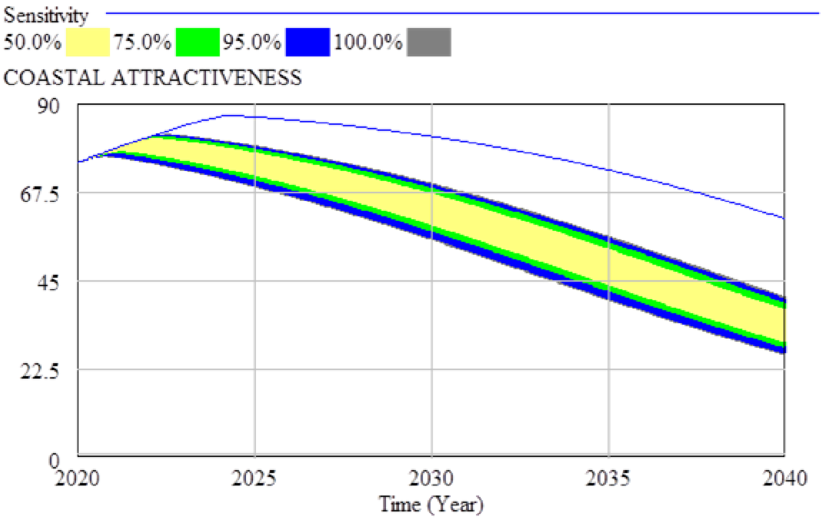
Click on the "Sensitivity Graph" button in the menu toolbar on the left-hand-side of the screen:

This should open the following window showing the sensitivity of "Coastal Attractiveness" for "Tourism Capacity", including confidence bounds (indicated as percentage):



More specific instructions were needed to guide the partners through the sensitivity analysis and ensure a pragmatic and harmonized approach. We explain the procedure for **parametric sensitivity analysis** for the example of the Spanish Multi-Actor Lab. In the example the purpose of the analysis is to assess the sensitivity of selected key policy indicators for changes in the policy settings (alternative management options) defined in the model. The four policy indicators (model outcomes) are:

1) agricultural nutrients in the Mar Menor Lagoon (a stock measured in ton nitrogen)
2) agricultural pressure on water resources (dimensionless index in range 0-1)
3) coastal-rural recreation potential (dimensionless index in range 0-1)
4) total number of jobs (jobs)

A total of fourteen policy related parameters were included in the sensitivity analysis, related to water management, pollution control, tourism activity, water use and environmental education. In a **univariate analysis –** i.e. changing one factor at a time, each of the 14 parameters X_i was varied over it's full range by

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running the SD model two times. First with a 'worst case' or minimal estimate $X_{i,min}$ and then with a "best case" or maximal estimate $X_{i,max}$. The **final** values of each of the 4 policy indicators Y_j are obtained for the two parameters settings and converted into a generalized, dimensionless sensitivity index S_{ij} in the range 0-1:

$$S_{ij} = \frac{Y_j(X_{i,max}) - Y_j(X_{i,min})}{(Y_{j,max} - Y_{j,min})}$$

where $Y_{j,min}$ and $Y_{j,max}$ define the full range of the indicator Y_j and are used to normalize the index. This normalization facilitates the comparison across indicators. The outcomes of the sensitivity analysis are shown in Figure 6 and should first be verified against knowledge of the real system (expertise and data). The most sensitive combinations help identify the most influential policy interventions.

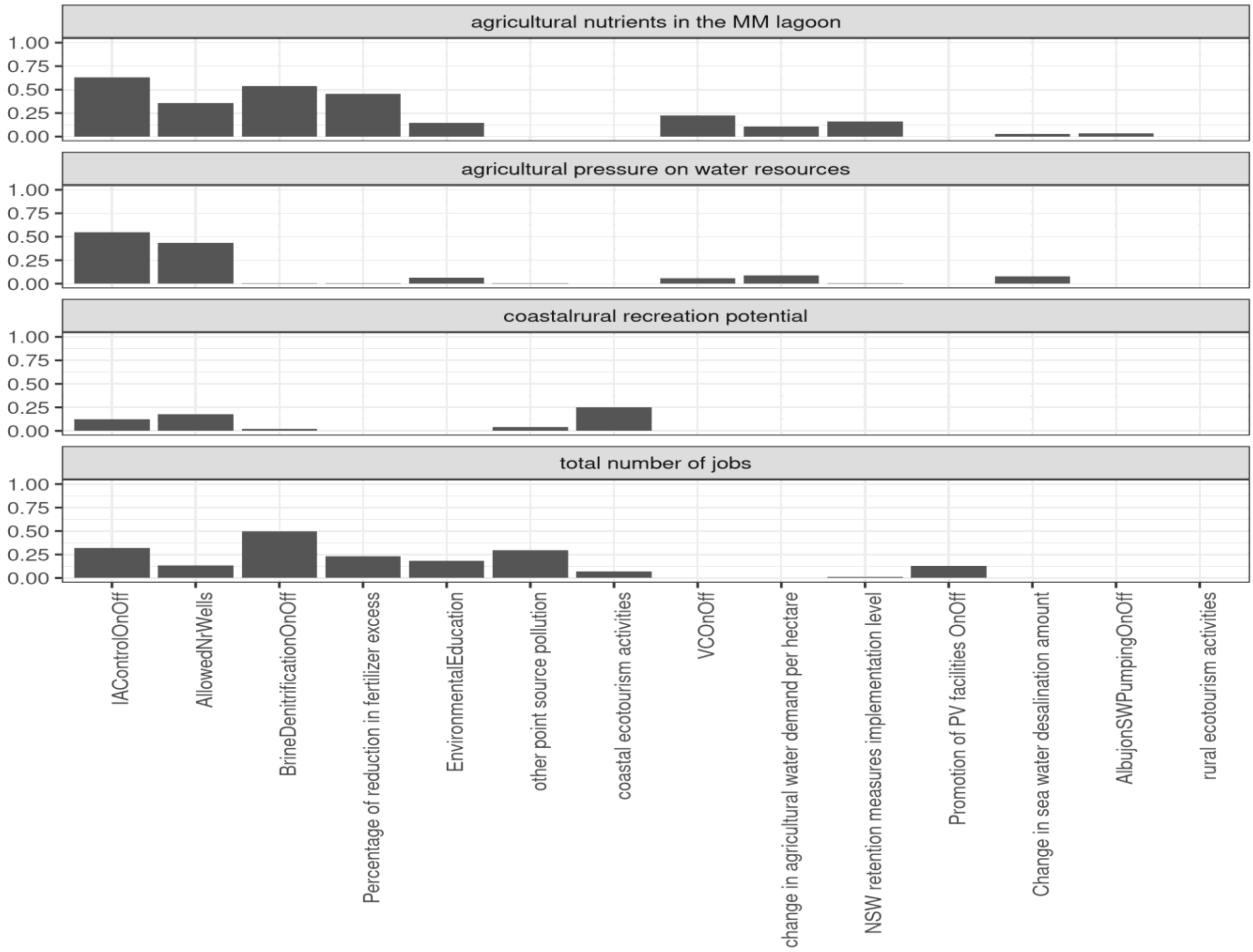

Figure 6 Parametric sensitivity of selected indicators for a selection of 14 different policy settings for the Mar Menor region (Martínez-López et al in prep).

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In this case the analysis was done automatically by running the model with an R script. Alternatively, the analysis can also be done manually by running the VenSim model multiple times, but the workload and chances of committing errors will increase with the number of parameters and indicators. As a comprise one can use the VenSim Monte Carlo tool discussed earlier and change the parameters one at a time over their range (univariate application). The outcomes can then be exported to Excel for further processing.

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3. CONFIDENCE BUILDING - MAL SURVEY

The majority of the MALs intuitively applied systemic confidence building tests to their models to examine the structure, behavior and policy implications during the design and implementation. The models were revised multiple times to make changes to the selection of variables, interactions and model structure. General recommendations regarding the principles of model validation and presentation of the models were issued. For example, the MALs were asked to add a policy dashboard to the models to collect key policy and scenario levers as well as indicators and to spreadsheets to organize the model input in case the model became too complex. The organization of the models also facilitates the testing of the models. As explained in Section 2 stakeholders and other target groups not involved directly in the modelling process are always a key to succesful confidence builing for SD models. For COASTAL the modelling trajectory started with the conceptual modelling and design of causal loop diagrams, first at the level of individual sectors (Tiller et al., 2021a) and subsequently for the integrated land-sea systems (Tiller et al., 2021b). Nevertheless, the MALs worked through different paths to develop confidence in their models, depending on the progress, scope and complexity of the models. A general, qualitative survey was considered necessary to document the process of confidence building and identify any challenging aspects of the model validation.

Table 3 Confidence building survey – overview of tests by the MALs on model structure, model behavior and policy testing.

MODEL STRUCTURE TESTING	Multi-Actor Lab	Way each aspect was handled
Briefly explain how you verified the structure of your model in the following respects: **1) Selection of variables and parameters;** **2) Model boundaries and level of detail (scope);** **3) Model feedback structure;** **4) Equations used;** **5) Extreme conditions;** **6) Engagement of stakeholder to obtain feedback on the structure of your model** **If an aspect of the model was not verified, please explain why not.**	MAL 01	• **Selection of variables and parameters**: the purpose of the stock-flow models (water management for the Oudland polder and decommissioning wind farms) served as starting point for the design but was adjusted during the project after exchanges with our actor partners. From this we identified the stock variables and key interactions. Parameter identification depended on the equations while quantifying the system relationships. Parameter values were determined based on a survey with assistance of the actor partners. • **Model boundaries**: the model boundaries (external drivers and level of detail) are linked to the model purpose. In particular for the Oudlandpolder system model more detail was added, for example the time resolution was adjusted to 1 day to address operational decisions such as canal water intake in the model. The scope of this model is still being discussed although the scenarios for climate change, land use cover and crop schemes have been completed. • **Equations**: these followed the (re)design of the model architecture. Equations were verified using the dimensional unit proofing tool of VenSim and step-by-step verification of the model behavior. • **Extreme conditions**: we added RCP6.0 and RCP8.5 climate scenarios to the model after discussing their relevance with the project partners in Rochefort. • **Stakeholder engagemen**t: although the stakeholder were intensively engaged in the design of the causal loop diagrams they have not been involved in decisions on the model structure. We feel their contribution is more

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		appropriate in the validation of the model behavior (policy indicators and implications).
	MAL02	**Selection of variables and parameters**: The initial pilot stock-flow models (wetland salinity regulation; shift from conventional to integrated farming; shift from a seasonal Sun/Sea/Sand tourism destination to a sustainable destination with expansion of the tourism season), served as starting points for the design of the model. Several adjustments were made as the project progressed based on exchanges with ourh actor partners and SH, improved understanding of the socio-ecological system of the area, and familiarization with the modelling environment. From the pilot SD models, we kept critical variables and interactions which were well understood by our SH and they were well expressed based on equations and look ups. In the most updated version of the model, we have added new parameters based on surveys with our SH and actor partners. **Model boundaries**: the model boundaries (external drivers and level of detail) are linked to the model purpose, and they provide a useful framework for the discussions with our SH. However, some parts could be improved in the future. In particular for the wetland, the model describes well the effect of restoration efforts on an annual basis (restoration of natural flows), but it could be useful to be able to change the resolution to 1 month ot 1 week or 1 day to address in more detail the restoration decisions. Similarly montly resolutions would also be useful to better understand the dynamics in tourism and agriculture. The scenarios for climate change, land use cover, transition to integrated/organic farming and restoration efforts have been completed. **Model feedback structure:** Based on the COASTAL methodology, which created iterative communication links between researchers, actor partners and stakeholders, we have adjusted the integrated MAL02 SD model to be able to address key topics which emerged for the case of SW Messinia. This type of

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		communication has increased confidence in the relevance and applicability of the model's feedback structure, which is further enhanced by its direct relation and comparability to key management indicators of the Common Agricultural Policy (CAP), the Water Framework Directive, and the Natura 2000 management directives; as well as its ability to facilitate scenario modeling and quantification of key parameters and interactions/exchanges among various socio-economic sectors and between rural and coastal condtions
		• The integrated MAL02 SD model is structured to address the basic components for achieving the common vision of the area developed during the first MAL workshop). However, the followed structure has allowed us to add many more information (e.g. ecosystem services) which we think that they can be useful in the future.
		• The integrated MAL02 SD model consists of several views (sub-models), which are separately developed and quantified. In relation to the common vision of the area, some key topics and problems (and their interactions) that we seek to find solutions for in SW Messinia are:
		  ○ The role of cooperatives in achieving the transition from conventional to integrated and eventually organic farming practices (e.g. branding and marketing, negotiation strength, certified production, agrotourism). How will this benefit farmers' well-being, and be enhanced in the coming years with links with future projects and business opportunities.
		  ○ The expected benefits of the transition (conventional to integrated/organic farming) on: i)*the environment* (e.g. use of groundwater resources and salinization risk, use of chemical pesticides and fertilisers, water quality); ii) *the characteristics of olive orchards* (e.g. soil organic content; soil erosion, soil biodiversity, vegetation cover); *iii) the well-being of farmers* (e.g. cost for fertilising and pest

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		control; olive-oil price); *iv) the branding and marketing of local products, v) the attractiveness of the landscape and the promotion of agrotourism* ○ The effect of seasonal (mass) tourism on (and associated feedbacks: i) *the environment* (e.g. use of groundwater resources and salinization risk, beach degradation); ii) *the land use change trend* (olive orchards to built-up land) and associated impacts on the area's character and *naturalness*. ○ The urgency for wetland restoration actions to prevent the collapse of the ecosystem and to secure and enhance the: i) *biodiversity conservation and development of eco-tourism; ii) fish production and food security; iii) area attractiveness and tourism,* • **Equations**: the equations followed the (re)design of the model architecture. Equations were verified using the dimensional unit proofing tool of VenSim (unit check) and step-by-step verification of the model behaviour • **Extreme conditions**: We have added RCP8.5 climate scenarios to the models after discussions with project partners in Rochefort and have also considered the implementation of no – measures for the restoration of the Lagoon under any conditions • **Stakeholder engagemen**t: Stakeholder were intensively engaged in the design of the causal loop diagrams however they were not involved in decisions regarding model structure. They have on the other hand provided feedback, during the second MAL workshop, that was useful for improving some stocks like the role of the cooperatives in the transition (from conventional to integrated/organic) within agriculture, and also improve some values relevant to all parts of the model (e.g. expected number of tourists)

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	MAL03	• **Selection of variables and parameters**: The SD (System Dyanmics) model for this coastal case has two sub-models that quantify land-sea inter-sectoral and coastal water and nutrient exchanges. The selection of variables and parameters in this targeted SD model inclusion and representation of key quantifiable system interactions and associated components and variables from the co-created CLD (Causal Loop Diagram) with stakeholders. The variables and parameters were also selected in view of facilitating further investigation of relevant development and road map scenarios with the SD model. The ability to quantify the SD model variables and parameter was judged based onthe availability of quantitative observational data, model results, and other types of information according to the inventory of data and models developed in WP2 for MAL3. The model structure and variable-parameter quantification were tested, adjusted and re-adjusted through multiple initial test calculations, and structure and result discussions with local partners and stakeholders. The final model setup with a realistic base case quantification was decided on after these test calculation and discussion rounds, based on the research team's and local actors'-stakeholders' expert judgments of results and their realism in represent known case conditions that the base case quantification aimed to represent. • **Model boundaries and level of detail**: The model boundaries (external drivers and level of detail) are linked to the model purpose. With regard to detail level, the co-created original CLD was too complex to be taken further as a whole into the SD modelling. Thus, the level of detail was reduced to focus on relevant main coastal development issues and key land-coast-sea interactions for the MAL3 case, for which data/evidence-based quantification was also possible. The model domain boundaries are physically-geographically given by the topographic water divide determining the whole hydrological land catchment area of the local MAL3 case: the Norrström drainage basin and surrounding

		coastal zones and their local catchment areas. In addition, MAL3 is also a cross-scale case, with local coastal conditions significantly dependent on as well as contributing to drive whole-sea eutrophication conditions. This is why nutrient (phosphorous and nitrogen) loads - and the freshwater discharges carrying these and to large degree determining load magnitudes - from land to sea are included as key variables for the model's coastal land-sea interface boundary; this allows for direct model result comparison with policy-determined regulatory targets that need to be reached for these loads according to the internationally agreed Action Plan for the whole Baltic Sea. Overall, boundary conditions are given as recent-current average conditions, from which possible shifts can be further investigated for different development and roadmap scenarios of change, considering what the different scenarios imply for input water flows and nutrient concentrations by scenario-related climate and sector land/water-use conditions at the land surface of the representative MAL3 coastal hydrological catchment. • **Model feedback structure**: Considering key interactions in the underlying co-created CLD and data and model (result) availability for quantifying these, two key topics were identified as both robustly quantifiable and highly relevant to MAL3 problems in need for solutions: ○ Cross-(sub)system/sector water flow (quantity, availability) exchanges, and their implications for the key land-sea interaction of seawater intrusion into fresh coastal groundwater (deteriorating water quality); and ○ Cross-(sub)system/sector exchanges of nutrients and their waterborne loads (thereby relating directly to the above water flow perspective) through the hydrological catchment that constitutes the MAL3 model domain to the sea, through the coastal boundary. This is a key land-sea interaction as it affects coastal and marine water quality and eutrophication in direct relation to corresponding effects that the same

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		nutrient load propagation has on inland water quality and eutrophication. Moreover, the relation of the nutrient loads to the regulatory targets of the Baltic Sea Action Plan feeds back to (possible new) policy and management measures for meeting these targets that should in turn affect concentration input variables in the SD modeling. ○ The integrated MAL3 SD model thus consists of two sub-models, which are separately developed and quantified to address each of the above topics and problems that we seek to find solutions for in this coastal case. These sub-models are further also directly connected through the water flow variables that affect and thus are consistently included and accounted in both the water exchange-availability sub-model and the water quality sub-model. Therefore, some water flow outputs from sub-model 1 (for water quantity, availability, and seawater intrusion) are used as explicit inputs to sub-model 2 (for nutrient exchanges and loads affecting and linking inland and coastal-marine water quality). ○ Confidence in the relevance and applicability of this feedback structure for the SD model was established by i) the underlying actor-stakeholder co-created and validated CLD, ii) its direct relation and comparability to key management indicators of the Baltic Sea Action Plan, iii) its ability to facilitate scenario modeling and quantification of key water availability and quality variables for and interactions/exchanges among various socio-economic sectors and between rural and coastal-marine condtions. • **Equations used**: Equations representing the key interactions between sectors are primarily based on data, models, and model results published in peer-reviewed literature. In addition, the equations used in the two SD sub-models honor, not just local for each interaction, but also overarching catchment-scale (i.e., whole MAL3-scale) fundamental physical water and nutrient mass balances as general key constraining conditions for the land-sea and inter-

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		sectoral water and nutrient interactions and exchanges. These constraints, combined with the unit consistency checks performed in Vensim, ensure a physically consistent description of the modeled MAL3 system. • **Extreme conditions**: We have considered RCP4.5 (corresponding to an average precipitation increase by around 11% over the coming decades compared to current conditions) as representing likely future climate conditions for MAL3b in our SD scenario modelling for this case. However, we have in complementary model sensitivity analysis also tested more extreme wetting conditions of 15% precipitation increase (i.e., up to around RCP8.5 conditions of average precipitation increase by 14%), as well as (unlikely average, but still occassionally possible) drier conditions with precipitation lowering by 15%. Overall, model scenario and sensitivity analysis results, also discussed and validated with MAL3 actors-stakeholders, confirm the model's ability to reasonably represent and quantify various conditions, including impacts of more extreme or divergent from expected future climate changes. • **Engagement of stakeholder to obtain feedback on the structure of your model**: During two multi-actor workshops, the unified regional CLD and the identified main problem aspects, as well as the SD model structure and results from model sensitivity analysis and possible change/development scenarios have been discussed and validated with the MAL3 actors-stakeholders. Decisions on final model structure and quantification have been made by the research team, considering but not dictated by these actor-stakeholder discussions and validation inputs.
	MAL04	• **Selection of variables and parameters**: We started from a simple structure focused on the main objectives of COASTAL. This was based on the CLDs built during a multi-actor workshop and on our own expertise in modelling and about the territory. From the beginning, the division of the model into 5 main sectoral submodels (water, agriculture, shellfish farming, infrastructure and

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		population) seemed obvious. We then adapted the model's structure iteratively through meetings with stakeholders. Per sector, we met actors at least twice to discuss their specific submodel and how it may connect to other submodels. They notably helped to identify the output variables of interest (KPIs) and the input decision variables (choice parameters) considered in their real-world management. For instance, the list of factors encouraging the conversion of agriculture towards an agroecological model was agreed upon with all the agricultural partners and corresponds to concrete levers of transformation that they observe in their work. We then filled the gaps between these variables (intermediary variables and equations) either based on stakeholders' knowledge, on our own knowledge or on existing models (SWAT for the water model). We presented the final structure of the model and lists of decision variables and KPIs to all the stakeholders (workshops and online consultation) for confirmation. • **Model boundaries**: the model boundaries were set in order to include the 5 sectoral submodels, their interactions and their external drivers. Because we look at a very large territory (10000 km2 with more than 1 million people) and endogenously simulate many drivers of its functioning as decision parameters of the model, only two external drivers were pertinent to add according to the stakeholders: climate change and agricultural prices. In terms of details, the time resolution was set to 1 month in order to simulate the seasonal behavior of the water cycle, water use, shellfish farming, agriculture and tourism. Along the iterative adaptation of the model's structure with the stakeholders, the number of simulated processes, equations and variables changed to ultimately keep only the ones that are necessary to connect the selected external drivers, choice parameters and KPIs. For example, we added a water distribution part to better include the effect of foreseen water storage for irrigation, while we removed an

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		unnecessary part on the evolution of demand for cognac (not a limiting factor when compared to planting rights). • **Equations**: the model's equations depend on the previously explained selection of variables and model boundaries. By order of priority, we set a given equation (formal relation between a set of variables) using formulas from established model, formulas designed with the stakeholders, or lookups, also codesigned. We verified the equations using the dimensional unit-proofing tool of VenSim and systematic verification of the model behavior. • **Extreme conditions**: we consider the RCP2.6, RCP4.5 and RCP8.5 to assess the effect of possible high variations in uncertain future climatic conditions. For other input variables, we tested drastic changes (both positive and negative) when compared to their current values and discussed the results with the stakeholders. We also checked for special conditions, like zero values or negative rates, and made them impossible in the model when relevant and possible. • **Stakeholder engagemen**t: as mentioned in the previous steps, the stakeholders were involved on all the aspects of the model's development. While we guided this development by proposing basic structures and mathematical formulas, we checked all the most important equations and interactions with the actors. Their qualitative validation of the results, during sectoral and multi-actor workshops, also validates, in part, the model's structure.
	MAL05	• **Selection of variables and parameters**: starting from the CLDs developed in the first phase of the project we identified the key state variables for the three development themes: ecotourism, ecofarming and freshwater fish farming. Auxiliary variables and parameters were identified step-by-step during

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		development of the three submodels and their integration (i.e. when defining the interactions). • **Model boundaries**: the model boundaries (including level of detail) where defined depending on the purpose of the model. Excessive detail was avoided by focusing on the key interactions and system feedback structure clarifying the problems examined. The ecofarming and fish farming submodels are based on a similar, reusable system archetype for transition (bass diffusion model). • **Equations**: these were defined by the logic behind the interactions in the model and verified using the unit consistency tool of VenSim. More intuitive mathematical structure were used when possible. For example, the tourism submodel uses an equation generating logistic growth controlled by the time to reach a certain critical level instead of a growth rate which is difficult to understand and communicate. • **Extreme conditions**: the behavior of the model under extreme conditions was examined qualitatively for key input drivers of the model such as the fish price, duration of tourist stay and the reinvestment of tourism revenues for marketing. Parameters settings were adjusted accordingly. • **Stakeholder engagemen**t: stakeholders were involved from the early stage of bulding the model. After the first round of sectoral consultations, the CLDs for specific sectors were generated to express their concerns and priorities. During further development of the SD model, we regularly went back to the stakeholders to fine tune the model or make adjustements whenever recommended. Based on the stakeholdes input, the project team decided on the structure of the model, while their opinion on the soundness of the model structure and functionalities was taken into consideration.
	MAL06	• **Selection of variables and parameters:** The integrated CLD (Causal Loop Diagram) developed with stakeholders during 6 sectorial workshops and

		multi-actor workshops was the origin of the SD (System Dyanmics) model. Because of the size, in terms of variables, and complexity, in terms of interactions and parameters of the CLD, we identified main partial problem domains based on the interactions categories identified by stakeholders and developed 1 stock-flow submodels for each of the problem domains. The final SD model fully integrates 7 stock-flow submodels. Several new variables that were not present in the CLD were included in the final SD model in order to be able to calculate the values of some of the key performance indicators or in order to allow the correct simulation of specific solutions mentioned by stakeholders. • **Model boundaries:** The model boundaries (external drivers and level of detail) are linked to the model purpose to evaluate the implications of policy and business solutions related to different socioeconomic coastal and rural activities in the watershed of the Mar Menor lagoon. In MAL6 the time resolution was adjusted to 1 year for te perdiod 1964 – 2070, as a balance between required detail for simulations and expected timeframe to see impact on KPIs relevant for long term policy development. • **Model feedback structure:** The model feedback structure was verified by means of testing model boundaries and the consistency of dimensions. We also idnetified which main feedback loops were present in the model, and if this still agreed with was reflected in the CLD presented by stakeholders. For example, as repòrted in Deliverable 14, one of the main feedback loops identified in the CLD that has driven the design of the stock-flow model is the feedback between Mar Menor water quality, environmental awareness, effectiveness of governance and the reduction of nutrients input to the Mar Menor lagoon via effectively controlling fertilizer use by public administrations. • **Equations:** The equations used in the SD model were selected primarily based on data available on historic trends (e.g. observed growth rate of irrigated

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		areas, or changes in tourist overnight stays), quantitative model output, and model results published in peer-reviewed literature. The model was calibrated by collecting and using data for model initialization and parameter setting, partly also together with stakeholders through expert interviews, for example to discuss realistic expected growth rates of variables under different scenarios. • **Extreme conditions:** We downscaled 4 Shared Socioeconomic Pathways together with the RCP 1.9 to assess the effect of possible variations in uncertain future socio-politic and climatic conditions. In addition we tested the impacts of more severe climate change scenarios (RCP4.5). The sensitivity analysis to different maximum or minimum implementation of policy options (explained in section 2.2.2), as well as an optimization of policy and business solutions was performed to test input variables across a broad range. This was done automatically by running the model multiple times with an R script. • **Engagement of stakeholders**: During the first multi-actor workshop we discussed the integrated Casual Loop Diagram with stakeholders. During this meeting we asked participants to identify if any relevant problems, connections, or possible solutions were missing. We also showed the FCMs and the outcomes of application of different scenarios on KPI using the FCM based on the CLD. This helped to ubderstand feedback structures and obtain suggestions for improvement. During the second multi-actor workshop the structure of the pilot System Dynamics model was discussed in detail with stakeholders to increase confidence and guarantee its legitimacy. All 7 sub-models integrating the System Dynamic model were validated in terms of variables, structure, equations and data through an online questionnaire and subsequent discussion during the workshop. In addition, before and after the second multi actor workshop we performed expert interviews to validate and get feedback on pilot and advanced versions of the SD model. All this feedback

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		has affected the model structure, increasing the level of detail in some aspects and becoming more comprehensive, reflecting interactions between model variables and using most reliable data. Decisions on final model structure and quantification have been made by the research team, considering both expert and stakeholder validation inputs.

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MODEL BEHAVIOR TESTING	Multi-Actor Lab	Way each aspect was handled
Briefly explain how the behavior (time dynamics of response to scenarios and policy measures) was verified for your model and addressed for: **1) Model anomalies (apparently wrong patterns);** **2) Response of the model to extreme conditions;** **3) Response of the model to policy measures;** **4) Response to scenarios;** **5) Parameter sensitivity;** **6) Face validation: how did you engage your stakeholders/target groups in validating the model behavior, and how was their feedback used?** **If a model behavior aspect was not covered, please explain why not.**	MAL 01	• **Model anomalies**: behavioral anomalies were encountered a number of times during the technical implementation of the stock-flow models, examined when these occurred and addressed by identifying the cause and solution, adjusting equations or making necessary changes to the model structure. The source of each anomaly (model structure, equations or data) was systemically determined in this way. For example, a decision tree was added to the model to handle the prioritization of different measures and clarify the flow order. • **Extreme condition testing**: the response of the model to extreme conditions, scenarios and policy measures was handled in a similar manner, generally focusing on observed lack of or excessive sensitivities in the first place. • **Policy response**: was examined by qualitative and quantitative inspection of the time patterns for key model variables and policy indicators by the modelling team; • **Response to scenarios**: was examined qualitatively and quantitatively, using an automatic MatLab script to process the model output into aggregated bar charts for the seasonal and long-term variations for policy relevant indicators such as the crop water demand in the Oudlandpolder. • **Parameter sensitivity**: was examined by means of manual adjustment as well as customized control sliders and the use of the VenSim sensitivity tool.

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		• **Face validitation**: Behavior testing with stakeholders (face validation) was replaced by testing by the MAL modelling team. When results passed the face validation phase and the team was confident of the model response to scenarios and policy settings the results were always discussed first with the actor partners in the model design. External communication of model response to stakeholders and other target groups focused on the policy interpretation of scenarios (see policy testing).
	MAL 02	• **Model anomalies**: behavioural anomalies were encountered a number of times during the technical implementation of the stock-flow models. We examined when those occurred and addressed them by identifying causes and respective solutions, adjusting equations or making necessary changes to the model structure. The source of each anomaly (model structure, equations or data) was systemically determined in this way. For example, a link between salinity and restoration actions was added in the model to handle the extreme values of salinity (high and low) under no or continuous restoration efforts. • **Extreme condition testing**: the response of the model to extreme conditions, scenarios and policy measures was handled in a similar manner, generally focusing on observed lack of or excessive sensitivities in the first place • **Policy response**: The policy response was examined by qualitative and quantitative inspection of the time patterns for key model variables and policy indicators by the modelling team. The scenarios for policy implementation are linked to the SSPs (different time in implementation) and to local initiatives (different time in policy adoption).

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		• **Response to scenarios**: Reponses to scenarios were examined qualitatively and in some occasions quantitatively. For example, the contribution of cooperatives is examined qualitatively, while the effect of restoration is quantitively examined based on available publications. • **Parameter sensitivity**: Tested through manual adjustments, scenario modelling and Vensim Sensitivity tools • **Face validation**: The results from the SD model have been discussed repeatedly during two multi-actor workshops. During the second MAL workshop we validate the structure and the behaviour of the model based on a step-by-step presentation of its (basic) structure and its results. The final (3rd workshop) was used to further validate outcomes through the use of the 3Horizons methodology, and by using examples of changes occurred in the area during the beginning of the project. The decisions on final model setup and quantification for sensitivity and scenario analysis have been made by the research team, considering discussions and inputs from stakeholders and experts.
	MAL 03	• **Model anomalies** Model anomalies were largely identified through and in direct comparison with the physical constraints implied by overarching catchment-scale water and nutrient mass balances, and actually observed variations of water flows and water storages (surface and groundwater level variations) in the MAL3 case. Anomalies were minimised by systematic model quantification modifications, test runs and checks against these constraints, as well as by the unit consistency tests of the Vensim software. • **Response of the model to extreme conditions**: The response of the SD model to extreme conditions was addressed through complementary sensitivity analysis, with parameters varying outside

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		their current normal or likely future range, in addition to the scenario analysis (D19) that represents more plausible future climate and land use change trajectories. This has confirmed the model's ability to reasonably represent and quantify various conditions, including impacts of more extreme or divergent from expected future changes. • **Response of the model to policy measures**: The response of the model to the policy measures described in the BRM will be tested in D20, through four business and policy trajectories. These four measures assume i) a decrease in surface nutrient concentrations, ii) a decrease in subsurface nutrient concentrations, iii) a recovery and decrease in nutrient concentrations in sewage treatment plants and unconnected coastal sewage systems, and iv) an integrated combination of these three measures. • **Response to scenarios**: Complementary sensitivity analysis, with a range of model parameters varying outside their current normal or likely future ranges, has provided robust validation and confidence building for the model responses to the investigated future scenarios. The latter have considered the likely RCP4.5 climate change scenario in combination with four different shared socio-economic pathway (SSP) scenarios (SSP1,2,4,5) adapted and applied to the MAL3 case. The scenario results are reasonable and explainable, also in comparison with the results of the model sensitivity analysis for more extreme parameter variation conditions. Model sensitivity and scenario results have also been discussed and validated in the multi-actor workshops for MAL3. • **Parameter sensitivity**: The sensitivity of model results to parameter quantification has been tested in specific smodel sensitivity analysis considering variations in the range of ± 15-30% from the base case values of various key model parameters. Model responses were

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		checked for possible unrealistic over- or under-sensitive responses, which did not emerge from this analysis. • **Face validitation**: During two multi-actor workshops, results from SD model sensitivity and scenario analysis have been discussed with MAL3 actors-stakeholders. The Tableau platform was used in the 1st workshop to pedagogically visualize and communicate with the workshop participants about model interactions, impacts and feedbacks. The 2nd multi-actor workshop was more focused on exploring interesting/relevant results from model sensitivity and scenarios analysis. Decisions on final model setup and quantification for sensitivity and scenario analysis have been made by the research team, considering but not dictated by the actor-stakeholder discussions and inputs.
	MAL 04	• **Model anomalies**: the model's behavior was checked against observations as much as possible along its development in order to avoid carrying strong anomalies. Similarly, the regular meetings with the stakeholders allowed identifying wrong simulated dynamics, the source of which we then tried to find with them, when theoretical, or through simulations and model checking, when technical. We showed again all the found solutions to the stakeholders. In the end of the development, we dedicated the remaining time to checking and improving the accuracy of the model against observations (cf. Annex 4). • **Extreme condition testing**: we simulated the climatic scenarios against drastic changes in all the decision variables to observe how the model behaves under extreme conditions. These results were discussed with the actors during sectoral and multi-actor workshops and served, in fact, as basis to discuss about the BRM and the

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		necessity to act towards sustainability and resilience. We will also provide a global sensitivity analysis of the finalized model to further inform about its behavior. • **Policy response**: the response of the model to policy measures was verified together with its response to extreme conditions, discussing the results of changes in policy measures with the stakeholders. The global sensitivity analysis will also include the policy variables. • **Response to scenarios**: the simulated effect of climate change appeared as counter-intuitive for some actors. The issue at stake is not how the model responds in fact, since the magnitude of the simulated effects seemed plausible. The input climate scenarios themselves are more the issue, since they sometimes show a beneficial effect of an increasing climate, with more rain and so more water for the territory. We will thus have to be thorough when interpreting and communicating these results, explaining their uncertainty. The used scenarios are the regional version of the GIEC scenarios and remain the best available source to simulate future possible climate change. • **Parameter sensitivity**: it was tested through manual adjustments, scenario simulations and the VenSim sensitivity tool. • **Face validation**: the results of simulating all the policy measures under different conditions were shown to all the stakeholders during sectoral and multi-actor workshops, asking for their validation. Some selected results were also made available online with the possibility to comment them. The results of this consultation were discussed during a multi-actor workshop. A last workshop is planned to disseminate the results of our study (model and BRM). We may use this opportunity to obtain a formal validation of the model by the

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		stakeholders involved along its development (this is still under question, as well as the way to do so).
	MAL 05	• **Model anomalies**: some problems and errors were encountered during model development but their origin could be traced quickly and solved due to the strong focus on feedback cycles in the models and modular design. In the final stage a problem occurred with the trends in key indicators disappearing. This could be solved quickly using the causal tracing tool of VenSim. • **Extreme condition testing**: see remarks under model structure. • **Policy response and response to scenarios**: these were examined qualitatively (direction of change and nature of the change, for example a non-linear increase with saturation effect as expected). • **Parameter sensitivity**: the response to parameters was verified by examining the response to changes over de maximum range, using manual inspections and the VenSim sensitivity tool. • **Face validation with stakeholders:** during the multi-actor workshop, the stakeholders were updated with the model results. At the same time, the stakeholders's vision for future development of the Danube Delta region was used as cornerstone for the development of the business roadmaps. The validation of model behavior was achieved in a workshop setting, while for specific parameters, one-to one meetings were organised.
	MAL 06	• **Model anomalies**: Model behavior was verified by studying predictive patterns and events and checking for anomalies. The source of each anomaly (model structure, equations or data) was systemically determined corrected by adjusting the model structure, equations or data. In some cases, it turned out that we needed to simplify or add

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		some complexity to the model structure in order to obtain consistent outcomes. • **Extreme condition testing**: During model development we continusouly performed test runs with a range of parameter settings or changing input variables. If inconsistencies were found, we made adaptations to model structure or equations. In addition application of the model using 4 downscaled Shared Socioeconomic Pathways and climate change, testing the sensitivity to maximum or minimum implementation of policy options (see section 2.2.2), as well as optimization of policy and business solutions helped to further explore model behavior under a broad range of conditions. This was done automatically by running the model multiple times with an R script. • **Policy response**: Model policy testing was performed by means of parameter sensitivity analysis of maximum and minimum implementation of policy and business recommendations and checking the plausibility of the impacts on KPI. • **Response to scenarios**: This was tested by testing the plausibility of timeseries of model output for 4 different scenarios based on downscaled Shared Socioeconomic Pathways and climate change scenarios alone or in combination with policy and business solutions. • **Parameter sensitivity**: This was examined by means of manual adjustment of parameters and customized control sliders and through a univariate sensitivity analysis to parameters related with policy interventions. • **Face validation**: The model was calibrated by collecting and using data for model initialization and parameter setting, partly together with stakeholders. The first face validation was performed based on the FCM simulations of scenarios during the first multi-actor workshop. SD

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		model outcome regarding the impacts of all policy and business solutions under 5 scenarios on 10 Key Performance Indicators involving social, economic and environmental dimensions will be shown and discussed with stakeholders and experts in a last workshop the 3rd of June of 2022. This will focus on evaluation of the benefits of implementation of the policy and business solutions described in the BRM that was co-developed with stakeholders.

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POLICY TESTING	Multi-Actor Lab	Way each aspect was handled
Explain how the policy recommendations obtained with your model were verified on the following aspects: 1) Sensitivity of policy recommendations for changes in the parameter settings; 2) Sensitivity of policy recommendations for changes to the model structure: new variables, including boundaries, level of detail etc. 3) General usefulness: how was the contribution of the model to coastal-rural development discussed with your stakeholders and target groups, and how was this feedback used?	MAL 01	• **Parameter sensitivity**: policy testing focused at the level of scenarios rather than parameter settings and model boundaries. The development of the Oudland Polder model was based on feedback provided during regular meetings and the second multi-actor workshop with the VLM and other stakeholders that were considered relevant such as ILVO (Flanders Research Institute for Agriculture, Fisheries and Food) and INBO (Research Institute for Nature and Forest). During these meetings model focus shifted, partially also due to changes in the participants. • **Sensitivity for model structure**: while during the first meeting with VLM the model scope was mainly on hydrology and the effect of introducing separate compartments for agriculture and nature water management, in subsequent meetings land use management and climate change were considered more important. This shift in scope was mainly due to the realisation that a spatially explicit numerical hydrological model, which serves a different purpose, was already under development. • **Operational usefulness**: for the Oudland Polder model development continues and stakeholder consultation is focused on the comparison and interpretation of scenarios for the impact of climate change and crop schedules on water shortages. The key indicators for the Port and Energy sub model and policy implications have been tested and proven correct in technical terms. A "counterintuitive" drop in the total number of wind turbines was traced back to the turbine installment

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		scenarios and verified with alternative scenarios. The usefulness of this submodel was examined in survey (see Annex 1) and proof validated with some suggestions for further improvement. The model outcomes will be used to support the preparations for the Framework Agreement for the Oudland polder with scenario analyses, which demonstrates the usefulness of the model.
	MAL02	• **Parameter sensitivity**: policy testing focused at the level of scenarios rather than parameter settings and model boundaries. The restoration of the Gialova Lagoon wetland was based on feedback provided during regular meetings with experts in the field (researchers, fishers), and on the assumption that the restoration will be implemented during the coming years following the implementation of national policy. However, there are scenarios which describe what could happen if the policy fails implementation. During these meetings model focus

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		shifted, partially also due to changes in the participants and in the level of understanding. • **Sensitivity for model structure**: After the first MAL workshop, the model scope was mainly on hydrology, and associated links with agriculture and tourism, while few socioeconomic aspects were well described. Since then, following an iterative process with meetings and model validation we have now added several new parameters which all together represent in good detail the socio-ecological system within SW Messinia, and by that the model is more capable to holistically address the main topics of the region. • **Operational usefulness**: The implementation of the Vision of Stakeholders was the starting point of the model, and as this is vision is very much in line with the EU Green Deal and the Biodiversity strategy- especially in relation to the NATURA 2000 sites the model can be used to identify pathways and measure the progress towards achieving Common Agricultural Policy and Biodiversity protection targets, as well as identifying policy and bussiness solutions to improve this.
	MAL03	• **Sensitivity of policy recommendations for changes in the parameter settings**: For MAL3, the policy recommendation testing will be carried out by considering different sets of possible policy and business trajectories, in accordance with main requirements/implications of the MAL3 Business Road Map (BRM), translated into management actions that directly influence specific model parameters. This testing will consider management measures for regulation of nutrient input/output concentrations in different sectors, and will complement already provided information from completed SD model sensitivity and scenario analyses on the sensitivity of some policy effects (related to

		spatial land-use planning, and economic growth policy) to model parameter changes. Overall, our SD model testing and analyses so far have helped us model responses and their parameter sensitivies and how the model should be further used for operationalizing the BRM. • **Sensitivity of policy recommendations for changes to the model structure**: We will not test further sensitivity of policy recommendations to changes in model structure of the model, as we have already amply tested sensitivity, including for some policy effects (related to spatial land-use planning, and economic growth policy), and built confidence in the usefuless of the SD model structure also for representing and reasonably responding to changes related to such policy recommendations. In addition, a range of parallel quantitative process-based modelling studies for MAL3 have also greatly contributed to our overall BRM assessments and our understanding of how to translate various policy and BRM trajectories to relevant SD model quantification. • **General usefulness**: The SD modelling has helped facilitate relevant communication with MAL3 actors-stakeholders and joint identification of key intervention points and related BRM trajectories for this case. The SD simulation results have highlighted key sectors contributing to water quality issues in MAL3 and possible future trends in these contributions based on projected hydro-climate and socioeconomic development scenarios. We will also have one more workshop with our local MAL3 partners in the beginning of June, where results of testing direct BRM-related policy recommendations with the SD model will be discussed. This workshop will provide a basis for possible further refinement of policy recommendation testing with the SD model.

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		Overall, co-developing the SD modeling with MAL3 actors-stakeholders is beneficial but has also been difficult, as modelling experience and understanding is widely diverse among the different actors, and the modeling methodology and results could only be communicated with them in a fragments, making it relatively unclear, in particular for actors with little or no modelling experience. More frequent and iterative actor-stakeholder involvement could allow the SD modelling approach to be used in a more educational and/or exploratory way to simulate and analyse a wider range of scenario and business and policy road map alternatives.
	MAL04	• **Parameter sensitivity**: during our last multi-actor workshop, the actions proposed in the BRM, codesigned with the stakeholders, were put in perspective with the results of simulating changes in decision parameters representing different levels of implementation of these actions. We presented the results according to different themes of actions, either sectoral or intersectoral. For each theme, we opened a discussion among the stakeholders asking whether the modelling results support the actions recommended in the BRM or not. The fact that the subsequent discussions surrounded the actions to engage and their magnitude, and not the plausibility of the modelling results, shows that the model can inform to some extent policy design as it provides a plausible picture of the system's sensitivity to different actions (parameter values). • **Sensitivity for model structure**: the structure of the model was constantly aligned with stakeholders' views along its development, changing it in order to test new policy actions that they envisaged. As such, they could observe with us how changing the structure of the model can change the picture that it gives of different actions and of

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		the territory as a whole. We do not plan to test this sensitivity further, formally or qualitatively. We try instead to be transparent about the limits of the model's structure when communicating its results. For instance, the absence of spatial details, which limits the capacity to take into account some stakeholders' considerations, was the topic of several discussions during workshops. • **Operational usefulness**: the model was effective to help the discussion with the stakeholders and among them, providing a common objective basis of discussion that they *a priori* agree with. It was interesting to observe the evolution of stakeholders' point of view with their involvement in the model's development. As they became more acquainted with it, they relied more on it to discuss their arguments during the multi-actor workshops for instance. This is also because the model was tailored with them along recurrent meetings. This altogether shows the usefulness of following a collaborative modelling approach in order to support an efficient dialogue among various actors. Considering the future use of the model as a proper decision-making tool, the study probably raised the interest of some stakeholders in having such model available. However, the model in its current state does not detail enough a particular sector to make it useful for actors who still keep their own particular interests in addition to the common ones. The model may however serve as a basis to include a detailed sectoral model in a larger scale territorial one.
	MAL05	• **Parameter sensitivity**: parameter sensitivity of policy implications was tested for a selection of policy relevant parameter settings: emergency level and marketing fraction for tourism, fish price and area available for fish farming, crop price and fertilizer use for ecofarming, and the

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		time needed to reach the target level in the context of the Farm to Fork Strategy. • **Sensitivity for model structure**: the impact of changes to model feedback structure on the policy implications and policy indicators was not considered a priority because the model structure was considered adequate and any changes (adding or removing interactions) would not improve the model structure. An important exception was the testing of the reinvestment cycle of tourism revenues for marketing which clearly changed the model behavior. • **Operational usefulness**: development of the SD model enhanced the collaborative exchange of opinions with and between local actors, who brought in their extensive experience in Danube region policies, strategies and development measures that could be translated into variables of the Vensim model and further on conected by mathematical equations so as to obtain prediction on their complementary impact on the behavior of key indicators.
	MAL06	• **Parameter sensitivity**: Policy testing focused at sensitivity of the scenarios of external drivers and the implementation level of policy solutions and checking the plausibility of the policy impacts rather than parameter settings and model boundaries since these were already defined during the initial stakeholder workshops. • **Sensitivity for model structure**: The model structure and its potential to evaluate impacts of policy measures was continuously discussed with stakeholders during workshops and expert interviews and alternatives of model structure were tested during model development by the model development team. The model structure therefore follows the stakeholders expectations for which policy measures and external drivers can be evaluated.

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		• **Operational usefulness**: The model usefulness to evaluate effectiveness of implementation of policy and business solutions was the starting point of model development. This has not changed throughout the project and has been continously checked with the stakeholders and experts during workshops and expert interviews. Particularly during the second multi-actor workshop stakeholder feedback was obtained regarding the usefulness for policy development and evaluation. It is foreseen that te model will be available as a an operational Decision Support System to support the evaluation of different policy interventions and their impact on the KPIs for sustainable development of the region.

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4. REFLECTIONS AND RECOMMENDATIONS

Clearly, the workload for model validation will depend on the model scope, boundaries (level of detail) and structural complexity. In this respect it is worthwile to cross compare the different models in terms of the number of variables, degree the model is governed by exogenous factors, the number of outcomes and complexity of the feedback structure. Fortunately, VenSim models can be imported in the free Stella ISEE player[2] which can automatically generate a number of interesting model metrics. A number of these metrics such as the centrality, density, complexity and hierarchy index were proposed to analyze the structure of Fuzzy Cognitive Maps (MacDonald, 1983; Ozesmi and Ozesmi, 2004; Devisscher et al., 2016; Kokkinos et al., 2018). These are also useful to compare the structure of stock-flow models in terms of their degree of internal integration, external forcing and balance of the models. Models with a high number of external forcing drivers, as compared to the number of indicators (model output) score less on the complexity metric. This is because the dynamics is governed (at least in terms of the model structure) by external forcing rather than the feedback structure of the model. This does not necessarily imply problems with the model design but it could be worthwhile to reconsider the type and number of forcing variables used. Furthermore, the centrality of a model object is included. This metric measures the total sum of in- and outgoing direct connections (not considering their weight as for FCMs). Large extremes of this metric can be observed for the majority of the models and it could be useful to identify these objects and their role as well as the relevance of the connections in the model structure. System feedback is essential for any SD model and should help understand the problems from the perspective of the model purpose. It is also important for identifying any potential policy measures which intervene in the feedback structure by adding or removing feedback – thus modifying the behavior of the model. Model structure testing should also address whether the consideration of system feedback is appropriate. A typical example of the overshoot-and collapse archetype (Figure 7) has four feedback loops and 12 model objects, i.e. a ratio of 0.33. Clearly, the COASTAL models have a lower feedback ratio, which can be attributed to the fact that feedback was not the starting point for the designing the models. Nevertheless, feedback loops are present in all models.

Obviously, these metrics should be interpreted qualitatively and with care. Nevertheless, it is clear that all MALs faced similar challenges when it comes to analysing their models and validating the model structure and model behavior due to the large number of variables and interactions, with a similar degree of structural complexity – the number of system interactions per variable. This is one of the main reasons for following a pragmatic approach for confidence building, supported with the tools available in VenSim as long as their use does not become counter-productive.

[2] https://www.iseesystems.com/softwares/player/iseeplayer.aspx

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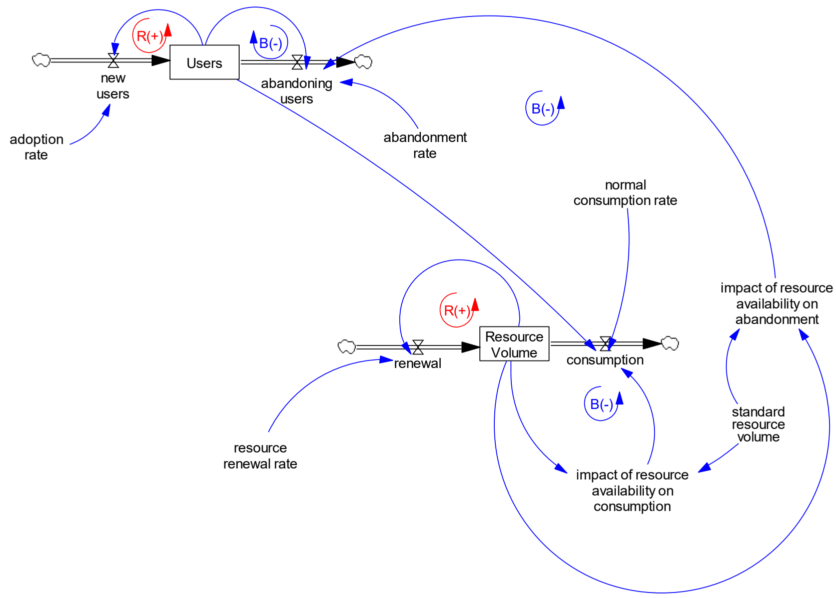

Figure 7 Generic archetype generating overshoot-and-collapse behavior with four feedback loops.

The purpose of the robustness analysis (Task 5.4) is to assess whether the positive impact of policy interventions is not affected significantly by changes in the uncertain exogenous conditions influencing the system (scenarios). In principle a similar approach as for the parametric sensitivity analysis can be followed if these factors can be represented by a specific parameter. Generally, however, these scenarios are represented by time series and manual comparison of their impact on the indicators is more appropriate. This type of assessment can be based on a comparison between the impact of the scenarios with the impact of changes in the policy settings (parameters). If the differences for the former are small compared to the latter the combination of policy settings can be considered robust.

Furthermore, SD models representing socio-environmental systems are intrinsically dynamic and their response to different policies should be considered over time. Although the final state of the system is certainly relevant for assessing the effectiveness of a management strategy (combination of policy parameters) the system and model evolve over time and intermediate states of the system may show a different or undesirable value for the policy indicators. The overshoot-and-collapse behavior model is a typical example. If only the initial and final state are considered in the overshoot-and-collapse model, the extreme behavior at which collapse occurs will go unnoticed. This situation can be addressed in principle by assessing the parametric sensitivity at multiple times over the simulation time. A more complete picture of this transient system behavior is obtained by comparing time graphs for the indicators.

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Model metric	MAL01	MAL02	MAL03	MAL04	MAL05	MAL06	Generic	World03
Nr. of variables V	396	149	366	767	132	218	8	412
Nr. of stocks	7	7	10	88	5	8	2	18
Nr. of flows	18	9	42	109	6	17	1	30
Nr. of equations[3]	228	63	285	354	65	156	3	210
Nr. of constants[4]	161	79	65	325	62	54	3	201
Nr of input variables (xls)	21	3	0	62	20	0	0	0
Nr of input constants (xls)	0	0	53	0	1	0	0	0
Nr. of table graphs	104	6	2	119	11	58	1	79
Nr. of submodels (sectors)	11	2	10	15	4	2	1	21
Nr. connections C	757	201	1054	2283	193	405	10	670
Nr of feedback loops F[5]	546	326	2939	13040	17	17	2	4055
Nr of Transmitters T [6]	157	84	68	132	63	55	3	194
Nr of Receivers R[7]	37	9	51	42	7	6	0	4
Complexity (R/T)[8]	0.24	0.11	0.75	0.13	0.11	0.11	0	0.0206
Density [9]	0.004767	0.005235	0.008021	0.002133	0.011862	0.008802	0.18	0.004
Mean Centrality[10]	3.8	2.6	5.8	4.4	2.9	3.8	2.5	3.25
Maximum Centrality	54	14	56	130	8	71	5	30
Hierarchy Index[11]	0.0003	0.0009	0.0008	0.0001	0.0014	0.0009	0.036	0.0004
Feedback cycle ratio[12]	1.37	1.11	8.10	12.60	0.14	0.08	0.25	9.84

Table 4 General model metrics for structural complexity and degree of balance between variables, constants and exogenous model input generated in ISEE player. Model endogenity should be as large as possible. Converters are constants, external input data and auxiliary variables.

[3] Using ISEE Player

[4] Using ISEE Player

[5] Traced automatically with MatLab function 'allcycles" (v21b) and a maximum search depth of 20, not counting cycles of length 2.

[6] A transmitter object has only outgoing connections. All scenario input variables and policy levers are by definition transmitters.

[7] A receiver object has only ingoing connections. All indicators (model output) are by definition receivers.

[8] A low complexity indicates the model dynamics is governed by external forcing, generally something to avoid in SD modelling. Dynamics should be endogenous i.e. generated by the model feedback structure.

[9] After Ozesmi (2004) we define the density as the number of variables divided by the square of the number of interactions.

[10] After Ozesmi (2004) we define centrality as the sum of in- and outgoing connections for a model object (variable or parameter)

[11] After Ozesmi (2004) and MacDonald (1983) the hierarchy index measures the systemic level of integration. A model with zero hierarchy index is fully democratic and well integrated. A fully tree-type model structure results in a hierarchy index of one.

[12] Number of feedback cycles of length > 2 divided by the number of variables.

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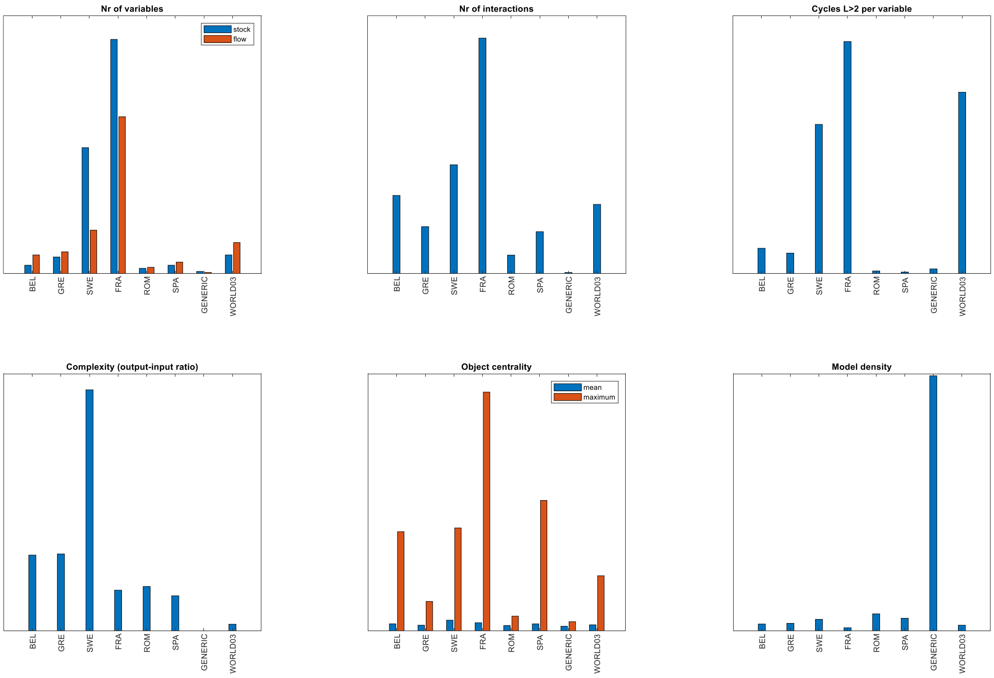
Figure 8 Comparative metrics for model structure applied to the MAL models. Model 7 is the generic archetype of Figure 7. Model 8 is a later adaptation of the World03 model[13].



The comparative metrics shown in *Table 4* and visualized in *Figure 8* highlight some structural differences between the MAL models. These are largely attributed to differences in the size and complexity of the models, rather than the presence of feedback. Feedback is present in all models although variations can be observed and follow the total number of interactions in the models. Obviously, the generic archetype is smaller in size (variables and interactions) but the density largest – i.e. the archetype structure centers around the interactions included.

Generally, multiple factors act simultaneously and will interact in the real system as well as in the model representation. A more complex, multivariate analysis can be carried out by varying multiple parameters simultaneously over their range and assessing the impact on the indicators using the Monte Carlo tool. This type of analysis can be considered an uncertainty analysis rather sensitivity testing and was not considered feasible and useful in the scope of the COASTAL project during the final year.

[13] https://www.thwink.org/sustain/articles/021_WorldChangeModel/index.htm

Finally, we emphasize the important property of complex systems and well-designed models representing these systems: the sensitivity for changes in the structure is generally much larger than for changes in individual parameters. Parametric sensitivity analyses can be useful for building confidence in the model structure and model behavior but should be complemented with interventions in the feedback structure to reveal innovative and unanticipated solutions to problems. This is a fundamental aspect of System Dynamics and SD modelling that is often overlooked. A technical solution is to add parameters to the models which act as switches to turn feedback loops on and off. Such parameters should be highly influential.

The following general recommendations are made to facilitate future model development, maintenance, testing, reuse and intercomparison:

- Modelling guidelines should not only address the general principles of SD modelling and technical functionalities of the software used but also provide specific guidance with respect to the number of variables to use, data handling, and consideration for important model features affecting the dynamics and potentially the usefulness of the model such as system feedback, time delays and systemic limitations. The use of stock, flow, and auxiliary variables should be proportional;
- Dimensional consistency is important for ensuring the validaty of equations and supported by most SD modeling software, including VenSim;
- Model development should be a gradual step-by-step process with ample room for intercomparison of models developed in a project, serving a mutual learning process. It is not a bad idea to start from generic archetypes. Furthermore, stock-flow modelling should start as soon as possible with quantitative policy analysis as an objective, it can go hand-in-hand with conceptual analysis;
- Model developers should be made aware that a broad scope and structural complexity of their models are not goals in themselves and can affect the work load for model testing and other work tasks such as the integration with scenario analysis and policy analysis. Keep models as simple as possible, but not any simpler (dixit Albert Einstein);
- Complex, repetitive numerical calculations cannot always be avoided (for example array operations). It is possible to include these directly in SD models but the design may benefit from keeping these separately in external input files. This depends on the degree of system feedback between the main model and these data.
- As much as possible, model dynamics should be endogeneous i.e. generated by the feedback structure of the model rather than by the time series imported from data files;
- Graphical design of these models is often a concern. However, one should realize that end-users and stakeholders are generally more interested in the model outcomes and policy recommendations rather than the underlying models as long as there is confidence in the model. Overly complex models are more a concern in terms of model design, maintenance and certainly reuse.
- Testing of overly complex SD models is often a challenge. Here, it can be useful to export the model results to other software platforms allowing more rapid analysis (R, MatLab, Python, ...).

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ANNEX 1 MODEL-SPECIFIC SURVEYS

MAL01 – The Wind Farm Decommissioning Model

In the framework of the European research project COASTAL, aimed at a sustainable coordination of offshore and onshore activities, a simulation model is being developed that can be used to examine the economic, logistical and ecological impact of decommissioning and installing wind turbines at sea in the medium to long term. For the period 2020-2050, the model calculates, on the basis of available data and plans (source: BOP, Wind EU, POM), indicators concerning energy production, park size, maintenance costs, employment and space requirements at sea and in the port. Technological developments are also taken into account (including the size of the turbines, related power and lifespan). A central indicator is the "decommissioning rate" - the number of turbines and physical volume that are dismantled per year. The aim of the model is to determine logistical bottlenecks, their causes and solutions in the (medium) long term, as well as the role of the offshore wind sector for regional economic development and the Port of Oostende in particular. To further develop the model we would like to get a better understanding of the limitations and possibilities.

QUESTIONS (open answers for telco, online alternative via score 0-5)

1) Do you see an added value/added value for such a medium-term projection, over other operational and strategic tools (MRP, cost-benefit analyses, scenario studies, smart monitoring, ...)?

2) If no, why not? If yes, can you indicate the added value?

3) Which factors are priorities when it comes to logistics, costs and employment related to wind turbine decommissioning?

4) Which factors are priority when it comes to environmental impacts?

5) Which parameters are particularly relevant in terms of technological evolution (in the context of energy production and decommissioning)?

6) For the turbines, there is a choice between offshore and onshore decommissioning, depending on the location and size of the turbines, as well as the available infrastructure. Which approach do you think is more likely?

7) What economic and logistical factors limit the port's capacity in dismantling (if onshore) and processing the turbines?

8) What economic and logistical factors are critical to increasing the port's capacity?

9) At this time, the simulation does not take into account multiple space use at sea. Which activities should be taken into account in the first place if the model were to be expanded in this respect?

10) Do you have any other comments that may be relevant to the further development of the model?

ANSWERS

Bijlage 2 Analyse resultaten COASTAL survey – Decommissioning model
(Wim Stubbe - Haven Oostende, Ben De Pauw – POM West-Vlaanderen, Jurgen Adriaen – Bluebridge, Steven Dauwe – VLIZ)

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Vragen	Belangrijkste factor(en)
1) Welke output ziet u als meest relevant voor een dergelijk model?	Aantal **ontmantelde turbines**/tijd
2) Welke factoren zijn prioritair in verband met de ontmanteling van windturbines?	De **totaalkost**
3) a. Welke factor is volgens u het meest bepalend voor de milieu-impact van ontmantelingsactiviteiten?	De **aard van het materiaal** en te ontmantelen **volume**
3) b. Welke additionele factoren zijn mogelijk ook relevant voor de milieu-impact van de ontmantelingsactiviteiten?	**Repowering** (mogelijkheid tot (selectieve) "finetunen" van ontmanteling via modulair ontwerp, vervangen van specifieke onderdelen) **Tweedehandsverkoop** voor gebruik onshore (weinig waarschijnlijk voor gecorrodeerde onderdelen, maar mogelijks geschikt voor sommige elementen)
4) Welke parameters zijn vooral relevant als het gaat om onderhoud van windturbines?	**Veiligheid** (mensen en schepen zijn kostbaarder dan drones, AUVs) Dalende energie-efficiëntie (vooral issue bij eerste generatie turbines)
5) Hoe ziet u de kost evolueren voor:	
Installatie	**Dalend** (hoewel schepen groter worden > gecompenseerd door hoger vermogen turbines)
Onderhoud	**Dalend** (onderhoud vanop afstand, digitalisatie, standaardisatie)
LCOE	**Dalend** (zie bijgevoegde papers)
6) Voor de turbines kan gekozen worden tussen offshore en onshore ontmanteling, afhankelijk van de locatie en grootte van de turbines, alsmede de beschikbare infrastructuur. Welke benadering lijkt u waarschijnlijker?	Combinatie > **kostfactor** is hier bepalend. Ruwe werk vindt op zee plaatst Handling op zee is ongeveer 3x duurder dan op land en risicovoller > snelle doorstroming naar achterland is wenselijk en waarschijnlijk
7) Welke logistieke factoren beperken de capaciteit van de haven bij de ontmanteling (indien onshore) en verwerking van de turbines?	Beschikbare ruimte, veiligheid en kosten
8) Welke faciliteiten zijn nodig om de afhandeling van oude windturbines mogelijk te maken?	Geen consensus over > mogelijks bepaald door juridische kwalificatie van onderdelen > "wat is afval, wat niet"
9) Nu biedt offshore energie werk aan circa 2 voltijdse werknemers per windturbine. Hoe ziet u dit evolueren met de tijd (2050)?	Geen consensus over > totale personeelsinzet wordt op verschillende manieren berekend

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10) Met welke activiteiten van meervoudig ruimtegebruik op zee zou in de eerste plaats rekening gehouden moeten worden?	Andere **hernieuwbare offshore energievormen en aquacultuur**

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ANNEX 2 MAL 2 – SOCIAL ECOLOGICAL MODEL OF THE VISION FOR A SUSTAINABLE MESSINIA.

In order to gain a better understanding of how the model predicts changes happening in the area and also validate the scenario outputs for sustainable or unsustainable futures, we used the 3Horizons framework (Sharpe et al, 2016). Stakeholders were asked to identify signs (or pockets) of a sustainable or non-sustainable futures that are currently evident in the area and focus in particularly in changes that move away from the vision or bring its implementation closer. The point of the exercise was to compare the outcomes of the model to the observations of the stakeholders for improving face validation. Some of the points identified are presented in the following table.

Fig. Diagram and images of the BAU and sustainable futures horizons

Table Sustainable and BAU evidence of the last two years

Pockets of a sustainable future (2020-2022)	**BAU evidence (2020-2022)**
General awareness for ecological issues among tourists and local residents	Increasing number of visitors at Voidokilia and Divari
Tourist information signs on Voidokoilia, (signs and fences)	Increased building activity without spatial planning
Monitoring of water quality of the lagoon	Dismantling of Protected area Management Body and delays in implementing the Protected area Management plan
Farmers educational actions	Increased drought conditions with impacts in the quality of the lagoon
Problem identification	Increased pressures for land use change (Agricultural to touristic)
Increased awareness of institutions and governance structures	Increased waste due to COVID (Masks and single use caps)
Reduction of agrochemicals (due to their increased prices and reduction of the olive oil price as well as COVID movement restrictions) Temporal	Increased number of tourists (road access instead of boat) due to COVID restrictions

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Project of the ephorate of antiquities and the university of Peloponnese for the protection of the cultural capital of the region	Seasonal tourist infrastructure (Beach umbrellas, beach bars etc)
Experience tourism increase	Forest fires and abandoning of olive groves
Temporal reduction of agrochemicals (due to economic issues – increased prices coupled with reduction in olive oil prices)	The bureaucratic model of producers' teams or cooperatives especially with respect to financial programs
Local stakeholders are starting to collaborate	Seasonal tourist infrastructure (Beach umbrellas, beach bars etc)

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ANNEX 3 MATLAB SCRIPT STRUCTURAL METRICS

```
% function  ModelMetrics(MALID)

clear all;
close all;
clc;

% fname_all = 'FeedbackLoops2.xlsx';

SheetNames = {'MAL01 Oudlandpolder' 'MAL02 SW Messina' 'MAL03 Baltic-Norrstrom' 'MAL04
Charente' 'MAL05 Danube' 'MAL06 Mar Menor' 'generic archetype' 'WorldChange'};
MetricLabels = {'Model objects (parents)' 'Stocks' 'Flows' 'Model Drivers'
'Transmitters' 'Receivers' 'Interactions' 'Cycles length 2' 'Cycles length > 2' ...
    'Total cycles' 'Average cycles length > 2 per connection' 'Average cycles per
connection' 'Complexity' 'Density' 'Average centrality' 'Maximum centrality' ...
    'Model hierarchy'};

search_depth = 20;

ModelSelection = [1 2 3 4 5 6 7 8];

NrModels = size(ModelSelection,2);

for MALID = ModelSelection(1):ModelSelection(NrModels),


ModelName = 'v3-combined';
DateString = date;
AuthorName = 'Jean-Luc de Kok';

LineNumber = 0;

% input  VenSim Causal Loop Diagram (mdl file, cleaned up first)

switch MALID
    case 1;
    V_Name_In = 'WaterSysteemOudlandv31.mdl';

    case 2;
    V_Name_In = 'MAL02_model_FINAL_18.mdl';
    case 3;
    V_Name_In = 'MAL3-SU model_TEST.mdl';
    case 4;
    V_Name_In = 'MAL4_IntegratedModel_Sharepoint_05042022.mdl';
    % V_Name_In = 'MAL04-STRIPPED.mdl';
    case 5;
    %V_Name_In ='36 MAL05 Combined Model.mdl';
    V_Name_In = 'MAL05-STRIPPED2.mdl';
    case 6;
    V_Name_In = 'ses_model_mmccv4_sspv2.mdl';
    case 7; % generic overshoot & collapse
    V_Name_In = 'ExampleSolarPanels.mdl';
    % V_Name_In ='TEST.mdl';
    case 8;
    V_Name_In = 'WorldChange.mdl';
end    %
```

```
fid_V_in = fopen(V_Name_In,'r');

% setting up FCM info (nr Parents, labels, FCM adjacency matrix,
% connection widths, Parent positions one screen)
MaxObjectsPerView = 1000;
MaxConnections = 10000;
MaxViews = 20;

LabelsView = cell(MaxViews,MaxObjectsPerView);
ObjectsInView = zeros(MaxViews,1);
NrView = 0;
NrFlows = 0;

% count nr of stocks
s = fgetl(fid_V_in);
c = strsplit(char(s),{',',',','|','='});
% StockLabels = cell(MaxObjectsPerView,1);
NrStocks = 0;
while (~strcmp(c(1),'$192-192-192')) % sketch section not reached
    s = fgetl(fid_V_in);
    c = strsplit(char(s),{',',',','|','='});
    k = strfind(s,'INTEG');
    if (k > 0),
       NrStocks = NrStocks + 1;
       StockLabels(NrStocks) = c(1);
    end

end
frewind(fid_V_in);

% count nr of input time series
s = fgetl(fid_V_in);
c = strsplit(char(s),{',',',','|','='});
% StockLabels = cell(MaxObjectsPerView,1);
NrModelDrivers = 0;
while (~strcmp(c(1),'$192-192-192')) % sketch section not reached
    s = fgetl(fid_V_in);
    c = strsplit(char(s),{',',',','|','='});
    k1 = strfind(s,'GET XLS DATA');
    k2 = strfind(s,'GET XLS LOOKUPS');
    k3 = strfind(s,'GET XLS CONSTANTS');
    if (k1 > 0 | k2 > 0 | k3 > 0),
       NrModelDrivers = NrModelDrivers + 1;
       StockLabels(NrModelDrivers) = c(1);
    end

end
frewind(fid_V_in);

VariableDetected = zeros(MaxViews,MaxObjectsPerView);
ParentID=zeros(MaxViews,MaxObjectsPerView);
ShadowParentID=zeros(MaxViews,MaxObjectsPerView);
IsParent = zeros(MaxViews,MaxObjectsPerView);
IsShadow = zeros(MaxViews,MaxObjectsPerView);
```

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```
% read VenSim model until sketch info section
s = fgetl(fid_V_in);
c = strsplit(char(s),{',','|'});
LineNumber = LineNumber + 1;
% step 1: retrieve all Parents
while (~strcmp(c(1),'$192-192-192')) % sketch section for first view (submodel) not
reached
    s = fgetl(fid_V_in);
    c = strsplit(char(s),{',','|'});
    LineNumber = LineNumber + 1;
end

% build up list of ALL variables
S_Parent ='';

% first retrieve variables from VenSim model
NrVariablesView  = 0;
ViewID = 1;

% read VenSim sketch info for Causal Loop Diagram line by line
s = fgetl(fid_V_in);
LineNumber = LineNumber + 1;
c = strsplit(char(s),{',','|'});


% step 1: retrieve all variable labels, view and object ids

while (~strcmp(c(1),'///---\\\')) % end of model not reached

    cc =   strsplit(char(s),{' '});

    if (strcmp(cc(1),'\\\---///')), % next view - skip 4 lines

        for i=1:4,
            s = fgetl(fid_V_in);
            LineNumber = LineNumber + 1;
            c = strsplit(char(s),{',','|'});
        end
        ViewID = ViewID +1;
    end

    % start looking for interactions in view
    FlowObjectsDetected = [];


    if (strcmp('10',c(1)) | strcmp('11',c(1))) % reading new Parent line with label,
position, ...

        if (strcmp('11',c(1))) % flow object detected



            ObjectID = str2num(char(c(2)));
            FlowObjectsDetected = [FlowObjectsDetected ObjectID];
            NrFlows = NrFlows +1;
```

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```
            while (~strcmp(c(1),'10')) % read downwards to find label of flow
                s = fgetl(fid_V_in);
                LineNumber = LineNumber + 1;
                c = strsplit(char(s),{',','|'});
                ObjectID = str2num(char(c(2)));
                if (strcmp('11',c(1)))
                    FlowObjectsDetected = [FlowObjectsDetected ObjectID];
                end
            end

        end
        % done identifying flow objects
        NrOfFlowObjects = size(FlowObjectsDetected,2);

       if (NrOfFlowObjects  > 0)
          % assign label to all corresponding flow objects - used for connections in
step 3
           LabelsView(ViewID,FlowObjectsDetected) = c(3);
        end
        VariableDetected(ViewID,FlowObjectsDetected) = 1;

        % store label of variable and update nr of variables
        ObjectID = str2num(char(c(2)));
        NrVariablesView = NrVariablesView  + 1;
        LabelsView(ViewID,ObjectID) = c(3);
        VariableDetected(ViewID,ObjectID) = 1;


   end % go to next view

    s = fgetl(fid_V_in);
    LineNumber = LineNumber + 1;
    c = strsplit(char(s),{',','|'});

    % take final object id for this view to count nr of objects
    % ObjectsInView(ViewID) = 1+ObjectID;

end % all  variables identified
TotalLines = LineNumber


% for each view we know now which objects are connected to a variable and
% the label


% step 2 distinguish parents from shadow variables
NrViews = ViewID;
% ObjectsInView = ObjectsInView(1:NrViews);
NrParents = 0;
NrShadows = 0;

for i=1:NrViews,

    id = find(VariableDetected(i,:) == 1);
    NrParentsView(i) = size(id,2);

    for j=1:NrParentsView(i),
```

```
        NewVariable = 1;
        for k=1:NrParents % look for existing variable in master list
           if (strcmp(char(LabelsView(i,id(j))),char(ParentLabels(k)))),
              NewVariable = 0; % this is an existing variable
              ParentFound = k;
           end
        end
        if (NewVariable) % add to master list if new variable
           NrParents = NrParents + 1;
           ParentLabels(NrParents) = LabelsView(i,id(j));
           ParentID(i,id(j)) = NrParents;
           IsParent(i,id(j)) = 1;
        else % this is a shadow variable - identify parent ID
           NrShadows = NrShadows + 1;
           ShadowLabels(NrShadows) = LabelsView(i,id(j));
           ShadowParentID(i,id(j)) = ParentFound;
           IsShadow(i,id(j)) = 1;
        end


    end


end % end views


% crop master arrays for parents and shadows
ParentLabels = ParentLabels(1:NrParents);
ShadowLabels = ShadowLabels(1:NrShadows);

% identify stock parents
for i= 1:NrStocks,
    for j=1:NrParents,
        if (strcmp(StockLabels(i),ParentLabels(j))),
            id_stock(i) = j;
        end
    end
end


% define interaction matrix
A = zeros(NrParents,NrParents);

% step 3 reread file to retrieve all system connections
frewind(fid_V_in);
LineNumber = 0;

s = fgetl(fid_V_in);
LineNumber = LineNumber + 1;
c = strsplit(char(s),{',','|'});

NrConnections = 0;
ViewID = 0;

while (~strcmp(c(1),'///---\\')) % end of model  not reached
```

```
    cc =   strsplit(char(s),{' '});

    if (strcmp(cc(1),'\\\---///')), % next view - skip 4 lines

        for i=1:4,
            s = fgetl(fid_V_in);
            LineNumber = LineNumber + 1;
            c = strsplit(char(s),{',','|'});
        end
        ViewID = ViewID + 1;
    end


    if (strcmp('1',c(1))),  % causal interaction found

        ObjectID1 = str2num(char(c(3)));
        ObjectID2 = str2num(char(c(4)));

        if (IsParent(ViewID,ObjectID1)),
            senderID = ParentID(ViewID,ObjectID1);
        elseif (IsShadow(ViewID,ObjectID1)),
            senderID = ShadowParentID(ViewID,ObjectID1);
        else
            senderID = 0;
        end

         if (IsParent(ViewID,ObjectID2)),
            receiverID = ParentID(ViewID,ObjectID2);
         elseif (IsShadow(ViewID,ObjectID2)),
            receiverID = ShadowParentID(ViewID,ObjectID2);
         else
            receiverID = 0;
         end


        if (senderID ~= 0 & receiverID ~=0 & (senderID ~= receiverID))

            NrConnections = NrConnections + 1;
            A(receiverID,senderID) = 1; % identifying causal impact

        end


    end
    s = fgetl(fid_V_in);
    LineNumber = LineNumber + 1;
    c = strsplit(char(s),{',','|'});

end

%  collecting metrics (cf Ozesmi et al (2004) - Ecological models based on people’s
knowledge:
% a multi-step fuzzy cognitive mapping approach


id = find(isnan(A));
```

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```
A(id) = 0.0;

% for metrics definitions see Table 1
https://www.ecologyandsociety.org/vol21/iss4/art18/

id = find(abs(A) > 0);
NrParents = size(A,1)
NrConnections = size(id,1)

InDegree = nan*ones(NrParents,1);
OutDegree = InDegree;
Centrality = InDegree;
ParentType = InDegree;

for i=1:NrParents,

   InDegree(i) = sum(abs(A(i,:)));
   OutDegree(i) = sum(abs(A(:,i)));
   Centrality(i) = InDegree(i) + OutDegree(i);

   if (InDegree(i) == 0 & OutDegree(i) > 0)
        ParentType(i) = 1; % transmitter: only outgoing connections
    elseif (InDegree(i) > 0 & OutDegree(i) == 0)
        ParentType(i) = 2; % receiver: only ingoing connections
    elseif (InDegree(i) > 0 & OutDegree(i) > 0)
        ParentType(i) = 0; % ordinary: in- AND outgoing connections
    else
       UnknownLabelFound = ParentLabels(i)
        warning('Parent of unknown type - no connections - please check');
   end


end

% main cycle tracing algorithm

G = digraph(A);
z = allcycles(G,'MaxCycleLength',2);
NrLoopsLengthTwo = size(z,1)
z = allcycles(G,'MaxCycleLength',search_depth);
NrTotalLoops = size(z,1);
NrOtherLoops = NrTotalLoops - NrLoopsLengthTwo;

SDEVCentrality = std(Centrality)
MeanCentrality = mean(Centrality)
RatioStdevToMeanCentrality = SDEVCentrality/MeanCentrality
MaxCentrality = max(Centrality)

% identify transmitters, receivers and ordinary variables
id = find(ParentType == 1);
NrTransmitters = size(id,1)
id = find(ParentType == 2);
NrReceivers = size(id,1)
NrOrdinary = NrParents - NrTransmitters - NrReceivers

Complexity = NrReceivers/NrTransmitters
```

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```
Density = NrConnections/(NrParents*(NrParents-1))

Hierarchy = 0;
% average outdegree
Z = sum(OutDegree)/NrParents;
for i=1:NrParents,
   Hierarchy = Hierarchy +  (OutDegree(i) - Z)^2;
end
Hierarchy = Hierarchy*12/(NrParents*(NrParents-1)*(NrParents+1))

NrLoopsLengthTwo = NrLoopsLengthTwo
NrTotalLoops = NrTotalLoops

% loop ratios defined by ratio nr of cycles to potential maximum as
% estimated in  https://mathoverflow.net/questions/203119/how-many-simple-cycles-can-a-
graph-with-n-vertices-and-m-edges-have

% dimension parameter D - NOT USED
D = NrConnections - NrParents +1;
MaxCycles = 2^D -1;

LoopRatio1 = NrOtherLoops/NrParents
LoopRatio2 = NrTotalLoops/NrParents

Metrics(MALID,:) = [NrParents NrStocks NrFlows  NrModelDrivers NrTransmitters
NrReceivers NrConnections NrLoopsLengthTwo NrOtherLoops ...
    NrTotalLoops LoopRatio1 LoopRatio2 Complexity Density MeanCentrality MaxCentrality
Hierarchy];

% save metrics and adjacency matrix for this model
xlswrite('Metrics.xlsx',MetricLabels',char(SheetNames(MALID)),'A1');
xlswrite('Metrics.xlsx',Metrics(MALID,:)',char(SheetNames(MALID)),'B1');
xlswrite('Metrics.xlsx',ParentLabels,char(SheetNames(MALID)),'E1');
xlswrite('Metrics.xlsx',ParentLabels',char(SheetNames(MALID)),'D2');
xlswrite('Metrics.xlsx',A,char(SheetNames(MALID)),'E2');


end

% Metrics = xlsread('Metrics.xlsx','Overview','B2:I18');
% Metrics = Metrics';
% NrModels = 8;

h=figure('units','normalized','outerposition',[0 0 1 1]);
PlotLabels = {'Nr of variables' 'Nr of interactions' 'Cycles L>2 per variable'
'Complexity (output-input ratio)' 'Object centrality' 'Model hierarchy'};

% calibration factor potential evapotranspiration
for k=1:6, % run scenario for two different value of calibration of Epot

h= subplot(2,3,k);
switch k
    case 1;
        % bar graph total nr of model objects
        bar([1:NrModels],[Metrics(1:NrModels,2) Metrics(1:NrModels,3)] );
        legend({'stock' 'flow'},'Location','NorthEast');
    case 2;
```

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```
        % bar graph total nr of interactions between model objects
        bar([1:NrModels],Metrics(1:NrModels,7),'BarWidth', 0.25);
    case 3;
        % bar graph number feedback loops per stock
        bar([1:NrModels],Metrics(1:NrModels,11),'BarWidth',0.25);
        % legend({'indirect' 'total'},'Location','NorthWest');
    case 4;
        % bar graph model input (transmitters) and model output (receivers
        % + stocks)
         bar([1:NrModels],Metrics(1:NrModels,13),'BarWidth', 0.25);
         % legend({'model input' 'model output'},'Location','NorthEast');
    case 5;
        % bar graph max  and mean of centrality
        bar([1:NrModels],[Metrics(1:NrModels,15) Metrics(1:NrModels,16)]);
         legend({'mean' 'maximum'},'Location','NorthEast');
    case 6;
        % bar graph model density
        bar([1:NrModels],Metrics(1:NrModels,17),'BarWidth', 0.25);
        % ylim([0 1.1]);
end

xlim([0 (NrModels+1)]);
set(gca,'xtick',[1:NrModels],'xticklabel',{'BEL' 'GRE' 'SWE' 'FRA' 'ROM' 'SPA' 'GENERIC'
'WORLD03'},'fontsize',9);
set(gca,'XTickLabelRotation',90)
if ( k ~= 6),
    set(gca,'ytick',[]);
else
    set(gca,'ytick',[1]);
end
title(char(PlotLabels(k)));
axis square;

end

saveas(gca,'MAL-Metrics.jpg');

save Metrics;
```


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ANNEX 4 MAL4 MODEL QUANTITATIVE VALIDATION

In addition to consulting stakeholders (cf. Table 3), we (MAL4) also validated our model quantitatively, comparing its outputs with observed data. This validation was part of the model calibration process (to fix the values of free unknown parameters) to which we will dedicate a scientific publication. Here we provide summarized examples for some main output variables of the model. Deliverable D14 "Operational SD models for Coastal-Rural interactions" describes the structure of the model. The lists of calibrated inputs, with their values, and the data used to validate the model, with their sources, will be provided with the SD model. Plots comparing model outputs' with observed data are also included in the SD model so that users can directly assess the validity of the model.

Water streams flow

Our modelling of the hydrological cycle was a bit peculiar since it did not include any spatial detail – it is at the scale of the whole Charente River basin –, which is usually the case for hydrological models. While our decomposition in the model of the water cycle into several compartments (cf. D14) seems valid, based on documentation and stakeholder's feedback, some input values (constants or lookups) remain unknown because not monitored at the scale of the model. For instance, the relationship between the amount of rainwater and the amount of water that infiltrates the soil is typically studied at a very small scale, according to detailed information about the soil type, soil water content, the slope of land, etc., but not at the scale of a whole river basin. To simulate soil infiltration, we thus expressed *infiltration* according to three variables (two constants, *min infiltration coefficient* and *min infiltration coefficient*, and a lookup, *infiltration coefficient according to soil saturation*) that we calibrated (found the values of the constants and the shape of the lookup) in order to reproduce observed water streams flow. Figure A4-1 below shows that the model ultimately simulates quite correctly the water stream flow in the last downstream measuring station on the Charente River (Beillant), chosen as reference.

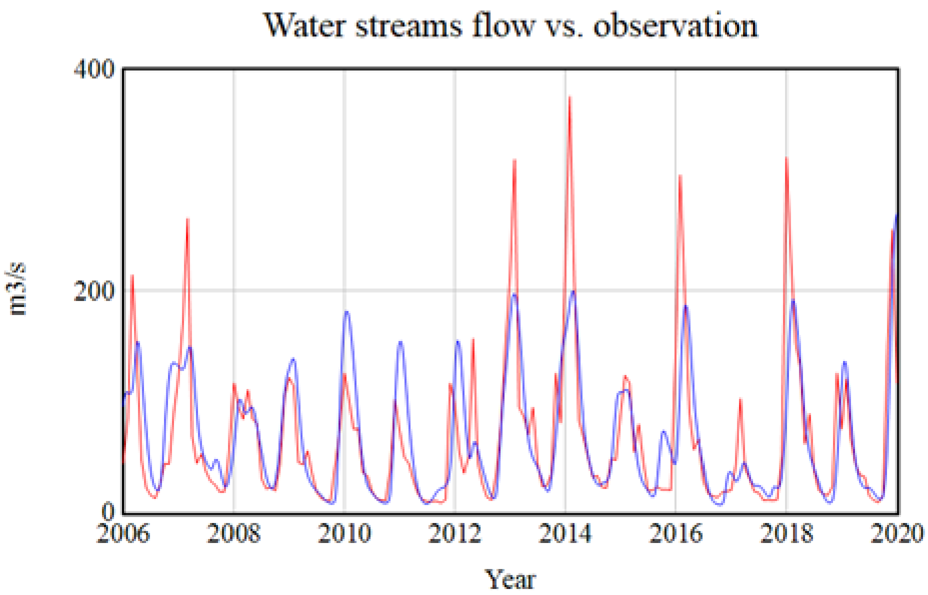

Figure A4-1: the model (in blue) simulates well the yearly pattern of the water streams flow (in red, from eaufrance, 2022). Although the model misses some high peak events, it fits the minimum observed flows, making it useful for the COASTAL objective of better managing water scarcity and avoiding deficits.

A useful aspect for developing our model is the SWAT model (spatial hydrological simulation model) that our team previously developed (Phelpin and Andro, 2019; cf. description in D14). It notably provided pseudo

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observation data for intermediary variables of the model, which helped us in calibrating all the free parameters of the hydrological model. This endeavor will be a main topic of the upcoming publication mentioned above.

Share of the UAA under agroecological farming

Following the view of stakeholder's, we model the conversion of the agricultural area from a conventional to an agroecological model according to five encouraging factors: the demand for agroecological products, the available supply chain, the difference in producer income, possible water deficits and the renewal of exploitation chiefs (cf. details in D14). The used equation has, by design, five unknown theoretical parameters that represent the relative influence of each factor in explaining the simulated agroecological transition (cf. detailed explanations in D14). We calibrated the values of these parameters with the objective to reproduce the past observed agroecological share of the UAA. Figure A4-2 below shows the final accuracy of the model, which seems acceptable to stakeholders.

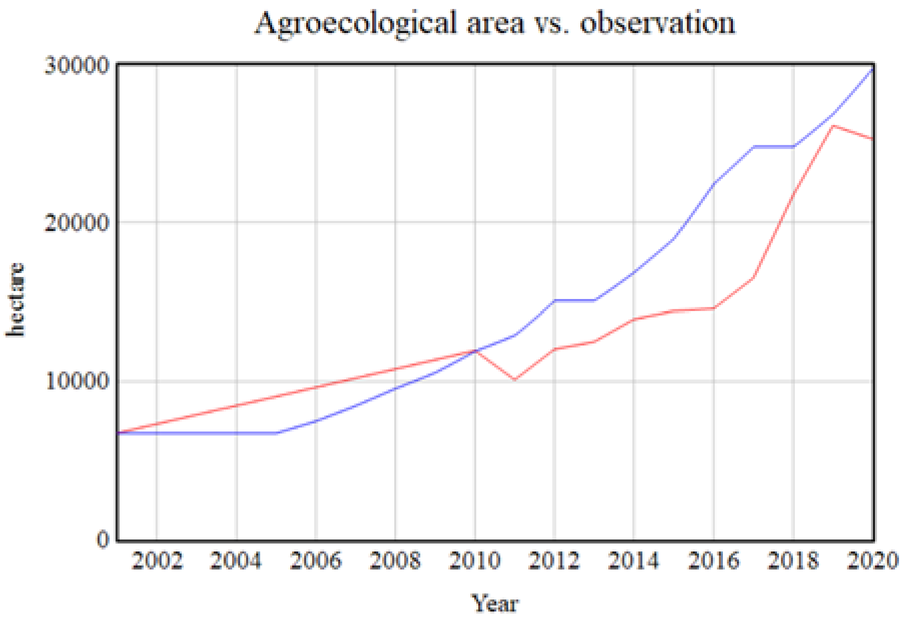

Figure A4-2: the model (in blue) simulates well the dynamics of the agroecological area (in red, from Agence Bio, 2020). Note that there is in fact a gap in the observation data from 2001 to 2010.

Total sales of oysters

The oysters' production model reproduces the typical three years production cycle, as verified with the stakeholders. Although the mortality of oysters is monitored well, the total number of oysters is not. However, we need to know the initial stocks of oysters in each year to run our model. We thus calibrated these values using observed mortality rates (Barbier et al., 2021) in order to simulate correctly past total sales of oysters, as figure A4-3 below shows.

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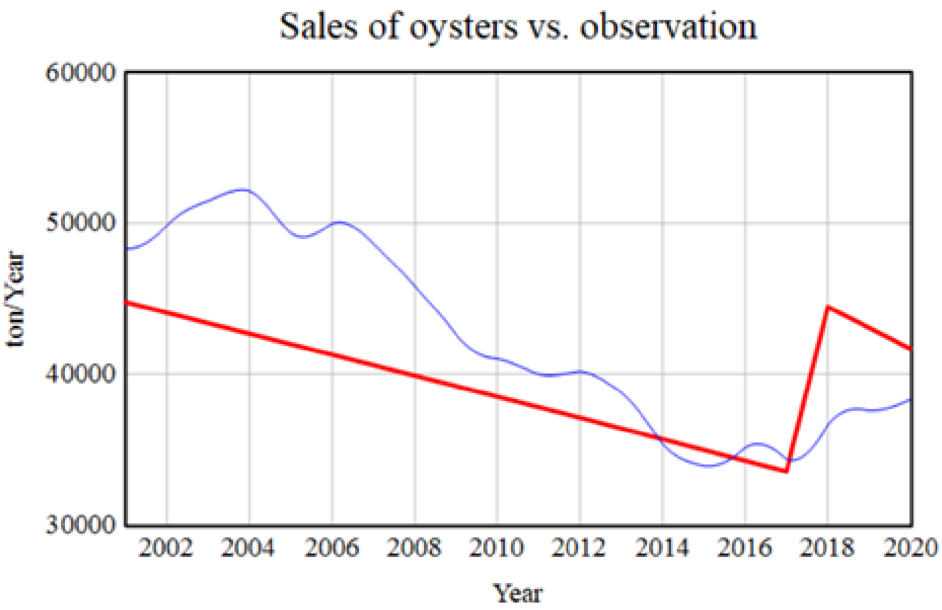

Figure A4-3: the model (in blue) simulates well the total sales of oysters (in red, from Agreste, 2020 and other years) and therefore, we can assume, the underlying production cycle. Note that the observation only includes four years (2001, 2016, 2018, 2020) connected by a line.

Agence Bio. (2020). Données départementales et régionales de certification au 31 décembre de 2011 à 2019. Les Chiffres Clés. https://www.agencebio.org/wp-content/uploads/2020/07/Donnees_Dept_depuis2011_AgenceBio.zip

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