COASTAL

Collaborative Land-Sea Integration Platform

Deliverable D19
Scenarios exploring land-sea interactions in six European coastal areas

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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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WHY THIS REPORT?

The Mediterranean, the North Sea, the Baltic Sea, the Atlantic Ocean, … They all played a vital role in European history. In times when travelling over water was easier than travelling over land, they connected not only people and trading centres, but facilitated also the exchange of ideas, knowledge, technologies and beliefs. Yet, the sea was also a threat: storms and spring tides flooded low-lying regions, took back land reclaimed from the sea, impacted businesses, and destroyed many lives. Notwithstanding this, people learned to deal with the unpredictability of the sea. Technological, socio-economic and ecological interventions reshaped Europe's coasts, and changed our relationship with coastal regions.

These impacts caused by human activity urge Europeans nowadays to redefine their position towards coastal and maritime environments. Rising sea levels, eutrophication, soil degradation, invasive species, habitat destruction and declining fish stocks are only some of the challenges that ask for effective answers the coming decades. COASTAL, the European Horizon 2020 project this publication is part of, stresses the importance of adopting an integrated and systemic approach, in which coastal-maritime systems are connected with their hinterlands when searching for these answers. Therefore the COASTAL consortium developed system-dynamic models tailor-made to the needs of six European regions, spread along the Baltic, North Sea, Atlantic, Black Sea and Mediterranean coasts. These models help to visualize and interpret the dynamic patterns characterizing coastal-hinterland interactions, and hence allow for a reflection on possible future developments in these regions. They are tools that can be used to assess the outcomes of interventions within these coastal regions, and therefore support the development of policy and business actions facilitating the transition towards more sustainable coastal-hinterland interactions.

In this report we present a set of scenarios, tailor-made for these system-dynamic models, that represent different plausible directions in which our societies could develop. These scenarios are descriptions of how the future may unfold the coming years and decades, based on a coherent and internally consistent set of assumptions about driving forces and their mutual relationships. For each of the regions participating in COASTAL, we first developed qualitative scenarios explaining the dynamics of a set of well-chosen variables defining the coastal-hinterland systems under scope. In a next step, these qualitative scenarios were quantified and used as a touchstone when assessing the robustness of policy and business actions proposed by stakeholders from the COASTAL regions. This publication should therefore be seen as complementary to the report 'Robustness analysis of business and policy actions for sustainable coastal-hinterland systems', in which the results of the robustness analyses are presented.

In the remaining part of this introductory section an overview is given of the methodology followed to construct the scenarios. The sections following upon this introduction – one section for each of the regions – give a detailed overview of the qualitative and quantitative elements constituting these descriptions, as well as the experts and stakeholders consulted when developing them. But more importantly, these sections also give a clear indication of the impact each of the scenarios may have on the coastal systems as we know them today. These regional sections are not interlinked, which means that you can read them separately from each other. Each of these regional reports can also be found on COASTAL's knowledge exchange platform.

WHAT IS A SCENARIO?

The term 'scenario' is used in many (scientific) disciplines, often with a (slightly) different connotation. In this report it refers to **a plausible and often simplified, though imaginative, description of the future of a societal system based on a coherent and internally consistent set of assumptions about key driving forces and relationships** (Zurek, 2007). These societal systems are considered complex adaptive systems, comprising a social, human-made, and a natural dimension (Westley et al., 2002). They are open towards their environment and constantly evolving, often in a non-linear way. During their evolution certain structures emerge through internal, dynamic processes, such as regulative frameworks, infrastructures, land-use patterns, technologies, etc. These structures are maintained during a certain period of time, even though the systems' components (e.g. citizens) are exchanged or renewed (Holling, 1978; Holland, 1995 and Cilliers, 2005).

Scenarios can therefore be used as an instrument to explore futures laying beyond vested mental frameworks; in scenarios societal systems do not necessarily have to stay within today's boundary conditions, nor do they have to display the same structural elements in the future as today. As can be read further on in this report, the COASTAL scenarios are **explicitly based on the assumption that future boundary conditions, driving forces, and their mutual interdependencies, may be subject to substantial change**. This automatically follows from the characteristics linking up the regions these scenarios are developed for, namely coastal areas already experiencing serious pressures due to climate change, agricultural transitions, industrialization, demographic changes, etc. Also the time horizon put forward in the scenarios, which is 2050 and beyond, asks for storylines including structural changes going beyond our current comfort zones.

WHY DO WE NEED SCENARIOS?

The big (global) problems we are confronted with today, such as climate change, biodiversity loss, water scarcity and resource depletion, are making people aware of the **complex and manifold linkages between human activities and natural systems**. They make us realize that the behaviour and dynamics of social and natural systems are difficult to grasp, and therefore difficult to fully understand and predict. There seem to be a multitude of linkages between social and natural processes, for example, between the way we organized our economic and financial systems, human behaviour, the spatial organization of human activities and the decline of biodiversity and ecosystem services - so many linkages, and of such different nature, that it sometimes even exceeds modelling capacity.

Also causes and effects are not always proportional: minor interventions in a system can have big consequences, and vice versa. Furthermore, these consequences can play out differently over time – in past, present and future contexts – and geographical scales. Local effects (e.g. temperature increases due to heat island effects) can be different from the impact measured at higher geographical levels (e.g. average temperature increase for Europe). The **behaviour and dynamics of social and natural systems** are therefore **surrounded by structural uncertainties**, which makes strategic planning and decision-making for sustainable development far from easy.

In order to be able to act effectively in contexts of structural uncertainty, we must organize our thinking accordingly and make use of instruments allowing us to deal with it (Tsoukas, 2006). Research has shown repeatedly that scenario building is one of the instruments suited for this purpose. Within a range of different tools helping us to generate new insights about future developments, **the process of developing and analysing plausible, though imaginative, descriptions of the future, has proved to be a useful approach to deal with fundamental uncertainties about the development of complex systems**. This kind of scenario building can be done either in qualitative terms, for instance by means of texts, word clouds or pictures, in quantitative terms, that is numerical data, or by combining both. Usually, a set of divergent scenarios is made, which allows to compare distinct assumptions about future changes (Zurek, 2007).

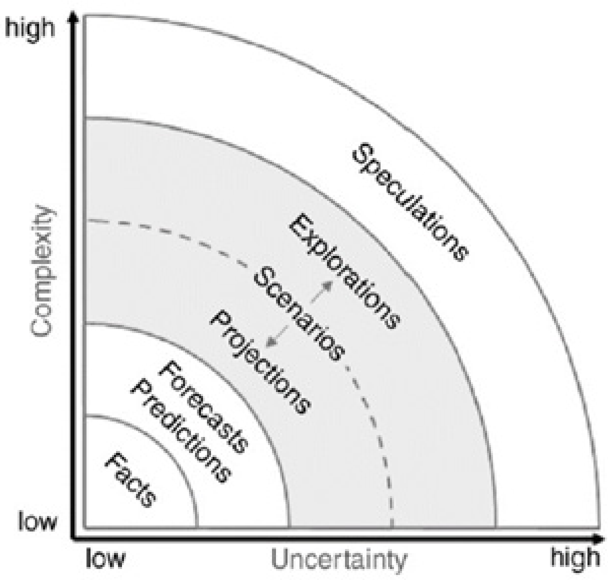

***Figure 1**. Depending on the inherent complexity and uncertainty of social and natural systems, other tools have proven to be appropriate to gain a better insight in future systemic evolutions (Zurek, 2007).*

In the context of COASTAL the **added value of scenarios** can be summarized as follows:

- One of the main goals of COASTAL is to investigate under what kind of societal conditions planned business and policy actions effectively contribute to the sustainable development of the coastal regions under scope. This goal reflects, in essence, the growing need felt by many stakeholders to **closely and thoroughly explore the long-term consequences of actions taken today**. Many social and environmental processes unfold over long time spans, and hence require comprehensive analyses over periods of 50-100 years and more. Scenarios including divergent, though plausible futures, allow us to gain new insights on how decisions taken today may work out under different circumstances in the mid- to longer-term (Zandersen, 2019). Furthermore, scenario building also helps to **shift attention from the past and present to potential future developments**. Especially when discussing measures responding to serious detrimental evolutions resulting from past policies, such as actions to adapt to climate change, it may be challenging to mentally detach from vested societal structures and processes (Nilsson, 2017). Scenario building can help in this.
- Scenarios and scenario building processes can function as an **opportunity to voice and elucidate conflicting opinions and world views in a structured way.** Though not always made clear, science and policy making are inextricably linked to making normative choices. They are not free of values and beliefs. This implies that assessing the effectivity of planned policy and business actions, as we do in COASTAL, cannot be done properly without being transparent about the reference points used for these assessments. By building a set of scenarios that represent different views on the socio-economic development of societal systems, and this in combination with several climate scenarios, COASTAL not only provides a platform to communicate about the uncertainties linked to different world views, but also creates a starting point to think through the implications of alternative regional development approaches. In addition to this, different scientific perspectives can also be given a place in a nuanced and transparent way.
- Sustainable development processes in coastal areas ask for integrated approaches taking account of the complex interactions between human society, climate and marine and coastal environments (Zandersen, 2019). Moreover, also evolutions further away may impact the development of these regions. Think for instance of port developments elsewhere in Europe, interventions in water catchment areas upstream, industrial investments in neighbouring regions and countries, and changing consumption patterns throughout Europe. It is the very nature of scenario exercises to **integrate across** this kind of diverse **issues, playing at different geographical scales and against varying time horizons, and their interactions**, and to discuss causal relationships between them (Zurek, 2007). A scenario building process could therefore be seen as **an interactive sense-making process**. It can help us to see what we couldn't see before and to generate new insights, **resulting in new possibilities for thought and action** (Tsoukas, 2006).

WHAT METHODOLOGY WAS FOLLOWED TO DEVELOP THE SCENARIOS?

We developed a three-step approach for the scenario building process in the COASTAL regions. Each of these steps is explained in the following paragraphs.

STEP 1: The development of coherent qualitative framework scenarios

As explained above, scenarios are plausible and often simplified, though imaginative, descriptions of the future of a societal system based on a coherent and internally consistent set of assumptions about key driving forces and relationships. This implies that scenarios are more than just imaginary narratives. Using an "internally consistent set of assumptions about key driving forces and relationships" means that a certain logic and rationale drives scenario building processes. A set of 'game rules' is used to give direction to the reasoning of the people involved in it. This way, comparable outcomes can be expected from similar scenario building exercises.

As a common ground to start from, the COASTAL regions were therefore asked to use the **Shared Socio-economic Pathways (SSPs)**. These are reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale in the absence of climate change or climate policies. The SSPs are one of three pillars forming a framework that has been developed to facilitate the production of integrated scenarios. The other two pillars comprise (1) **policy assumptions** and (2) **climate model projections** derived from, for instance, the Reference Concentration Pathways (RCPs) (O'Neill, 2014). In the context of COASTAL, the former equal the business and policy actions that are analysed in the report 'Robustness analysis of business and policy actions for sustainable coastal-hinterland systems', which complements this publication. Complementary to these business and policy actions and the SSPs, each of the regions also included climate data in their integrated scenarios by means of region-specific projections of precipitation patterns, hours of sunshine, sea level rise, air humidity and other relevant parameters.

Consequently, this three-pillar framework gives rise to a three-dimensional matrix representing **key determinants of structural uncertainty linked to societal development**. One of the determinants highlighted in this matrix is climate change. A second determinant are the assumptions underlying public and private policy making processes. And a third determinant of uncertainty is socioeconomic development, since a variety of different social and economic interventions can take place of which each combination leads to another societal constellation.

This third determinant of uncertainty, namely **socioeconomic development**, is further **detailed in the SSPs by means of an elaborate list of socioeconomic drivers**, such as population growth, economic growth, inequality, globalization, consumption, diet and technology transfer, that are categorized along the categories 'demographics', 'human development', 'economy and lifestyle', 'policies and institutions', 'technology' and 'environment and natural resources.' (A full overview of these drivers can be found in O'Neill, 2015 and O'Neill, 2017). Yet, the SSPs do not extend to the outcomes of these drivers, such as greenhouse gas emissions, land-use patterns, effects on agricultural production or water availability. Thinking through the consequences of (combinations of) these drivers is typically done in scenario building processes starting from the SSPs, hence the kind of scenario exercise of which the results are presented in this report.

Other important outcomes of the SSPs' socioeconomic drivers – outcomes that in the meantime have become completely impassable – are the exposure of societies to the (physical) impacts of climate change, such as extreme weather events, temperature changes or sea level rise, and their capacity to deal with this. Outcomes relevant to highlight from this perspective could then be the availability of the resources needed to decrease greenhouse gas emissions or the capacity of industries to transform their energy supplies. Socioeconomic drivers will, for instance, co-define the limits to autonomous adaptation, that is the range of adaptive measures that are readily accessible to individuals and organizations within a certain societal constellation. They will also determine the barriers policy makers are confronted with when trying to implement severe climate policies. Given the importance of climate change, the **SSPs are** therefore **positioned along two axes depicting, on the one hand, a range of challenges pertaining to mitigation and, on the other hand, a range of challenges related to adaptation** (see also Figure 2). Socioeconomic challenges to mitigation are defined as consisting of: (1) factors that tend to lead to high greenhouse gas emissions in the absence of climate change policy because, all else equal, higher emissions make that mitigation task larger, and (2) factors that would tend to reduce the inherent mitigative capacity of society (O'Neill, 2014). High emissions can be generated in a number of ways, each being a combination of specific drivers such as high population growth rates, energy intensive economies, carbon intensive energy supplies, etc. Socioeconomic challenge to adaptation, on the other hand, are defined as societal or environmental conditions that, by making adaptation more difficult, increase the risks associated with any given projection of climate change (O'Neill, 2014).

Within the space created by these two axes five SSPs are delineated (see also Figure 2). This implies that the development of the SSPs has been done through combining both inverse and forward approaches in a complementary manner (O'Neill, 2014). The definition of an outcome space to be spanned by combinations of challenges to adaptation and mitigation formed an initial field of reference that was then filled in by combinations of socioeconomic drivers that are hypothesized to lead to societal constellations confronted to a greater or lesser extent with mitigation and adaptation challenges. Narratives describing the societal constellations each of these five SSPs are referring to can be found in O'Neill (2015). In addition to this, a more detailed characterization of the socioeconomic drivers under each of the SSPs is published in O'Neill (2017).

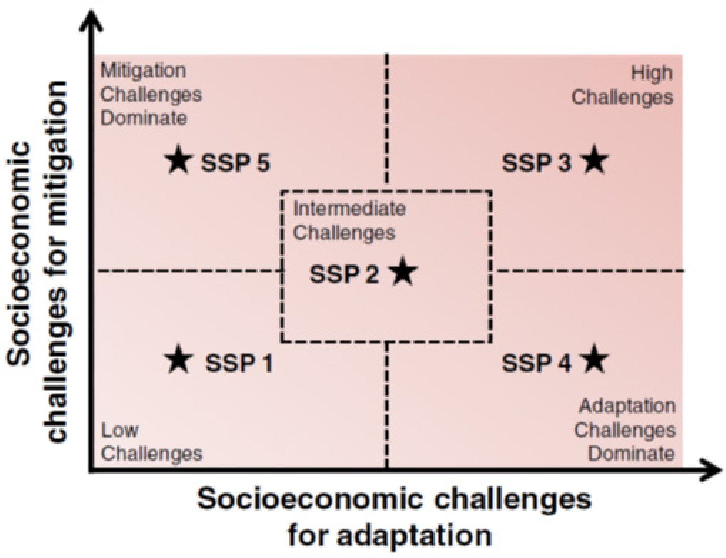

***Figure 2**. The 'space' spanned by the SSPs, divided into five 'domains' with one SSP located in each of these domains (O'Neill et al., 2014).*

Finally, we also consulted the **IPCC Special Report 'Global warming of 1.5°C'**, as it assessed, at that time, state-of-the-art knowledge of the environmental, technical, economic, financial, socio-cultural and institutional dimensions of a 1.5°C warmer world. COASTAL wants to align with the objectives set out in the **Paris Agreement**. The project's outcomes should therefore feed pathways that allow to limit global warming to 1.5°C by 2100. This IPCC report made clear that not one integrated assessment model could find a 1.5°C-consistent pathway for SSP3, and hence that the geophysical, environmental-ecological, technological, economic, socio-cultural and institutional characteristics of **a SSP3 world won't make it feasible to stay within the 1.5°C limit**. As a result, the project partners were asked to only use SSP1, SSP2, SSP4 and SSP5 as framework scenarios.

STEP 2: The development of qualitative scenarios at model level

With the SSPs as a clear starting point, the project partners were asked in a next step to downscale these framework scenarios to the level of their region or, in other words, the regional system they modelled. This was done by linking relevant drivers explained in the SSPs, which were developed for large world regions, with processes at lower geographical scales. In this context a clear distinction had to be made between processes that could be considered internal to the modelled systems and processes that had to be seen as drivers impacting the system from the outside. Only the latter, the system-external uncertainties had to become part of the scenarios.

In summary, this downscaling process was done in a way...

- **coherent across scales**, meaning that the scenarios explore what happens at case level in a similar logic as in the framework scenarios. They adopt a similar way of thinking and make the same assumptions about the future. Of course, this does not preclude substantial differences with regard to how the scenarios play out in each of the cases (Zurek, 2007).
- **respecting the drivers for change at case level**. In the context of COASTAL, the drivers that are relevant in each of the cases were identified throughout the stakeholder and modelling process (see also WP1 & WP4). In the next sections of this report, that is the case reports, a clear overview can be found of the models' variables used to enter the scenarios in the modelled systems and the SSP drivers that were downscaled and assumed to impact these variables.
- **informed by expert opinions**, so that an external and independent expert view can be included on how the complex interplay of multiple drivers could impact the modelled systems (e.g. Chen et al., 2020; Nilsson et al., 2017 or Zandersen et al., 2019). The case reports in the next sections give an overview of the organizations and experts involved in the scenarios building process in each of the cases.
- **validated by relevant regional actors** (e.g. Nilsson et al., 2017). Also a list with the regional stakeholders who were consulted during the scenario development process, can be found in the case reports in the next sections.

STEP 3: Quantification of the qualitative scenarios

Finally, each of the qualitative scenario descriptions was quantified with the help of figures from literature, additional modelling work, national and regional databases and, when necessary, expert judgements.

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SCENARIOS FOR THE CHARENTE RIVER BASIN AND ITS COASTAL ZONE

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CONTEXTUAL ELEMENTS INFLUENCING SCENARIO BUILDING

The collaborative workshops organized in the context of COASTAL highlighted the need for more integrative policies at the scale of rural and coastal areas. Many policies (e.g. water) still consider the upstream and downstream sectors separately. This is even worse for land-sea interface areas. Similarly, some aids or incentives are only aimed at professionals in a single sector of activity (farmers, shellfish farmers, tourism operators, etc.), whereas actions to strengthen land-sea synergies must be “territorial” and not sectoral, and therefore accessible to different economic actors. At the moment of writing, specific interviews with local stakeholders, in order to clarify and refine the proposals in terms of public action, are in progress. An integrated analysis will be provided at the end of the interviews, focusing on current and “to-improve” policies aiming at enhancing land sea synergies. Therefore, COASTAL’s work should be of great interest for local authorities and water managers in the area.

A large range of stakeholders (more than 60) involved in regional development or in natural resources management participated, at different stages, in the workshops. They will be able to use the project results to improve current institutions or to launch new structures. For instance, the SDAGE (water management scheme at the departmental scale) or the SAGE (at the river basin scale) can be appropriate places to develop meaningful indicators for the business roadmap, which we also developed in COASTAL. Two of the current coordinators of these commissions confirmed this. The interviews referred to above are also meant to explore those institutional land-sea links in local policies.

Furthermore, during COASTAL, we also took into account what other institutional bodies propose or reflect upon:

i. The “regional scheme for planning, sustainable development and territorial equality” (SRADDET) sets climate, air and energy objectives for the region in order to adapt to climate change, fight against air pollution and control energy consumption, both primary and final.

ii. The Neoterra roadmap (New Aquitaine region) aims to adapt the regional economy to climate change with different components (water, practices, innovations, water savings for agriculture, biodiversity).

iii. The Charente 2050 program aims to define scenarios preserving inland water resources in association with territorial activities.

iv. The “Varenne de l’eau” concertation defined trajectories and new practices to deal with the impact of agriculture on water resources (irrigation, water storage) and develop agricultural supply chains in the regional area, in the context of the climate change.

STAKEHOLDER INVOLVEMENT DURING THE SCENARIO BUILDING PROCESS

PROJECT PARTNERS

Throughout the scenario development process, local project partners were consulted to review the scenarios, and hence to correct and/or supplement them with additional information when needed. Representatives of the following organizations gave input for the scenarios:

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
CRANA	Chamber of agriculture	Agriculture and livestock farming, irrigation, economics, development	3	2	1	
FRAB	Professional federation	Organic farming, economics, development	4	2	2	
Chambers of agriculture at the department level (linked to CRANA)	Chamber of agriculture	Agriculture and livestock farming, irrigation, economics, development	2	2		
INRAE Bordeaux (33)	Public research institute	Economics, agronomy, agro-geography, political sciences, data management / GIS modelling	6	3	3	
Conchy consulting (linked to INRAE)	Consultancy bureau	Shellfish farming, science and decision making, collaborative processes	1	1		
INRAE Saint-Laurent-de-la-Prée (17)	Public research institute	Experts in coastal marshes and local development	3		3	

OTHER STAKEHOLDERS

To cover the full width of the scope of the scenarios, also the following organizations were involved in the scenario building process:

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Cogest'eau	Professional membership organisation	Water sharing in irrigated areas	2	1	1	
Ocealia	Cooperative	Conventional and organic farming	1	1		
BNIC	Professional membership organisation	Vineyards, cognac producers	1		1	
CRC	Professional membership organisation	Shellfish farming	1		1	
Maison REMY MARTIN	Private company	Vineyards, cognac producers	2		1	
Port La Rochelle and Port Tonnay Charente	Ports	Ports, infrastructure, blue economy	2	1	1	
Agence de l'Eau Adour Garonne	Public river basin agency	Continental and marine waters, water management	1		1	
SYMBO	Public-private water managers	Water management, hydrosystems, environment, WFD implementation	1	1		
GIP Littoral	Public body	Environment, coastal management	1	1		
EPTB Charente	Public-private water managers	Water management, hydrosystems, environment, WFD implementation	2	2		
DRAAF	Regional governmental authorities	Agriculture and agro-environment, food sector	2	2		
DREAL	Regional governmental authorities	Climate change, risks, natural resources	2	1	1	
DIRM	Governmental authorities	The Interregional Directorate for the South Atlantic Sea (DIRM) coordinates policies for the regulation of activities at sea.	1		1	
Pays Ouest Charente	Coastal and rural tourism	Coastal and rural tourism	1	1		
CFPPA	Public education	Education of young professionals and adults	1		1	
Conservatoire du littoral	Public agency	Preservation of natural resources and biodiversity in the coastal zone	1	1		
Region Nouvelle Aquitaine	Regional authorities	Regional planning, sustainable development and territorial equality (SRADDET)	2	2		

RATIONALE STAKEHOLDER SELECTION

Our participation in other studies and agro-environmental action plans within the Charente watershed (BAC Coulonge), as well as consultations with local partners on agriculture, shellfish farming and water management, allowed us to select a first range of key stakeholders relevant for the main issues of the territory. As a whole, 24 stakeholders with a coastal perspective and 30 stakeholders with a rural perspective attended the six sectoral workshops. In addition, representatives from project partners CRANA and FRAB attended every workshop and brought in their expertise on agriculture, agro-industry and water storage. In the first workshops, we also asked the participants about their main contacts relevant for our discussions. This allowed us to identify and invite new interesting stakeholders for the next workshops.

SCENARIO DEVELOPMENT APPROACH

We decided to work on the "scenarios" or "trajectories" from early on in the project, that is when the six sectoral workshops were organized at the beginning of the project (2018-2019). Some of the scenarios put forward by the workshop participants were more pathways in fact (Table 1). Some actions, such as the controversial water storage, came out in slightly different or complementary ways. Several trajectories concerned climate change and mitigation measures to deal with associated environmental and economic consequences. A likely increase in coastal population and the adaptation of rural and coastal activities to climate change were major sources of concern. This preliminary work served as a basis from which the stakeholders built their "desirable future" for the territory and the associated business roadmap.

Table 1. *Suggested trajectories for the territory as put forward during the six sectoral workshops. In columns: 3 rural workshops (green) and 3 coastal workshops (blue). In lines: The trajectories are grouped in themes by color.*

Scenario	AGRICULTURE	WATER SECTOR	ENVIRONMENTAL POLICIES AND TERRITORIAL DEVELOPMENT	PORT INFRASTRUCTURE ENERGY	TOURISM	SHELLFISH FARMING AQUACULTURE FISHING
1	current farming systems preservation of livestock breeding	change in public policies climate change and public demands	reduction of farming activity especially livestock systems and consequences	adaptation of infrastructure linked to sea level rise	impact of climate change on the coastline	consequences of climate change on coastal activities
2	development of organic farming	control of water resources and organic farming		development of solar and offshore windpower energies	development of digital technology and infrastructure	development of sustainable shellfish farming
3	sustainable agriculture and farming industries	change in wineproducing practices	mosaic of landscapes and activities preservation of the environment	decarbonization of territory to reduce environmental footprint	development of high-quality tourism	recycling and reusing waste
4	water storage	water storage	water storage in "bassines" and consequences	development of biomass energy sector	raising public awareness and education	changing the anthropogenic pressure
5	increase pressure on land	increased population in coastal areas	concentration of population in urban areas and big farms in rural zones	renewed public policies (climate change)	public policy to develop sustainable tourism	public policy for a better management of coastal wetlands

After this initial phase, we followed the common COASTAL approach. We organized three online meetings with our local partners (1/12/2020 and 25-26/01/2021) to prepare the 2021 multi-actor workshop. We also had preliminary discussions with key actors from several sectors: agriculture (14/12/2020 and 19/01/2021), ports (15/12/2020) and shellfish farming (11/01/2021). The workshop gathered around twenty participants. Together they formed a core group of stakeholders who covered all relevant sectors (cfr. Figure 1) and attended all the meetings. This allowed us to have more relevant and informed opinions. We saw the views and declarations of the participants evolve over time, as the discussions with other sectors progressed, and converged towards a common vision of the desirable future of the territory and its potential trajectories. (An overview summarizing the main workshops contributing to the scenario development process, can be found on the next page.)

Ultimately, our collaboration with the stakeholders allowed us, on the one hand, to identify the main external drivers of the land-sea system and, on the other hand, to describe three possible trajectories for the evolution of the territory:

- Trajectory 1 ("Towards a desirable future") implies a full implementation of the BRM towards the desirable future co-built with the stakeholders,
- In Trajectory 2 ("Improved current trends"), the development of collaborative and participative solutions is less extensive than in the first trajectory,
- Trajectory 3 ("Towards a fragmented territory") exacerbates different forms of inequality, due to the existence of multiple systems, which leads to social tensions.

An even worse trajectory ("Highway to nowhere") was suggested but eventually abandoned because of its proximity with trajectory 3, which seemed more relevant to the stakeholders in the end.

The next chapters of this report focus on the scenarios for the uncertain external drivers of the land-sea system in order to evaluate the sensitivity of the territory's dynamics to these drivers. This analysis should be considered together with our case's contribution to deliverable n° 20 "Robustness analysis of policy and business actions" in which we will detail and analyze the territorial development trajectories against these scenarios. This way we will be able to evaluate the costs and benefits of implementing our business roadmap for the Charente river basin and its coastal region, as well as the roadmap's robustness in the face of external changes. (If you are reading the case report, the case's contribution to deliverable n° 20 can be found in the next part of this publication.)

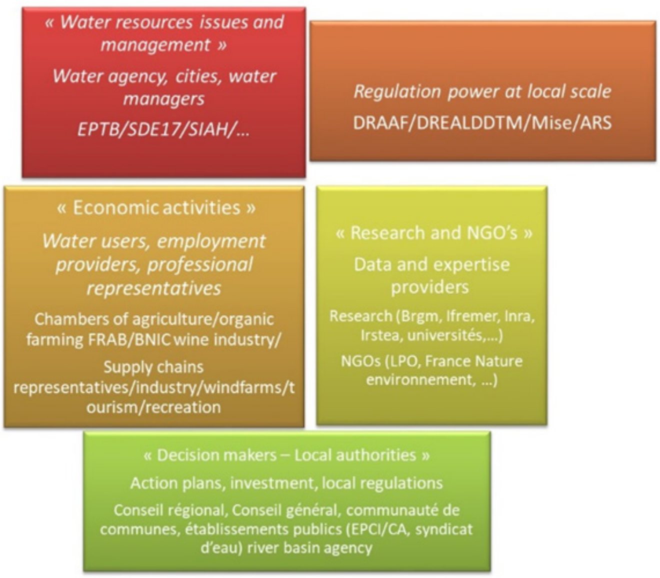
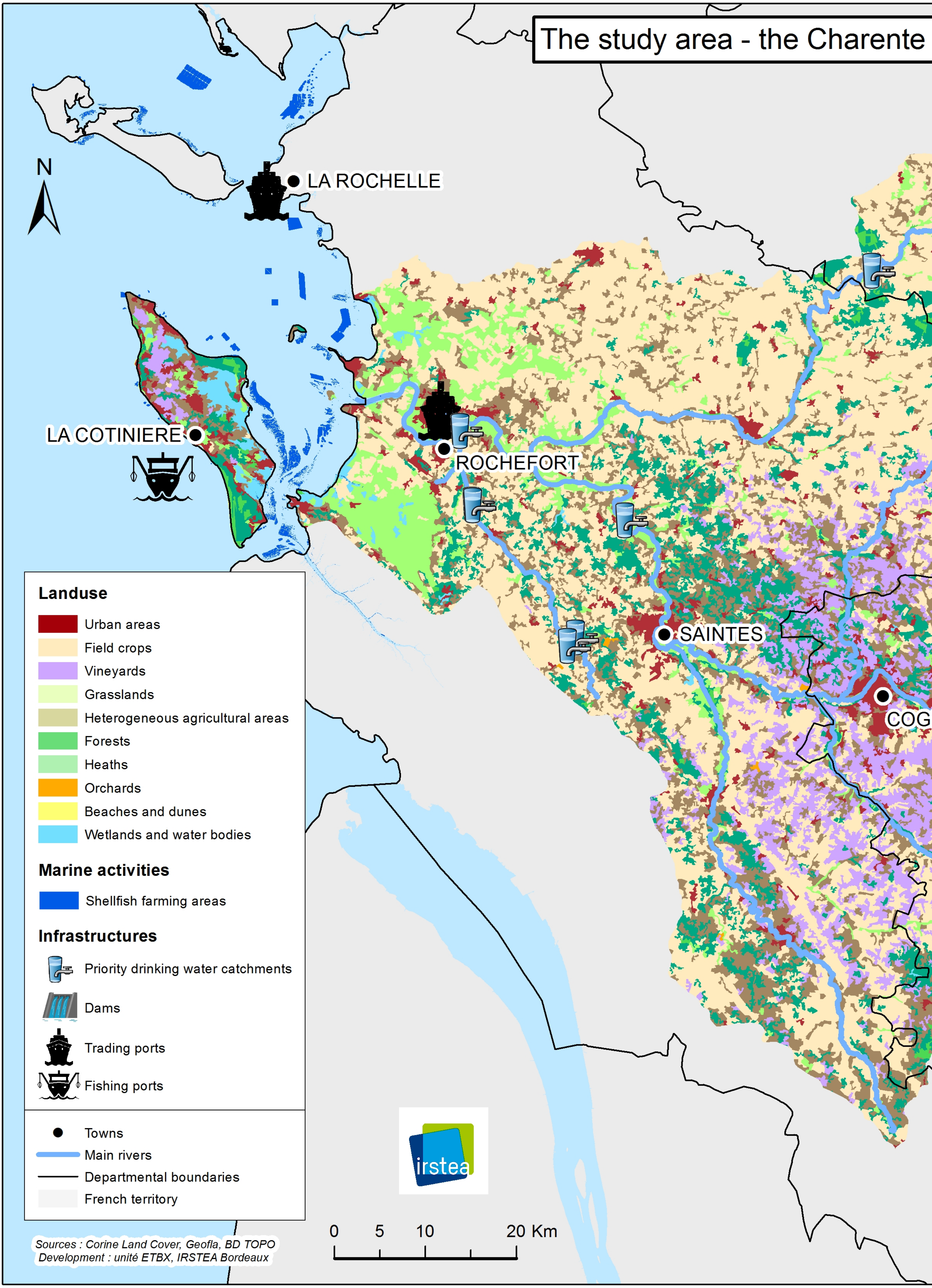
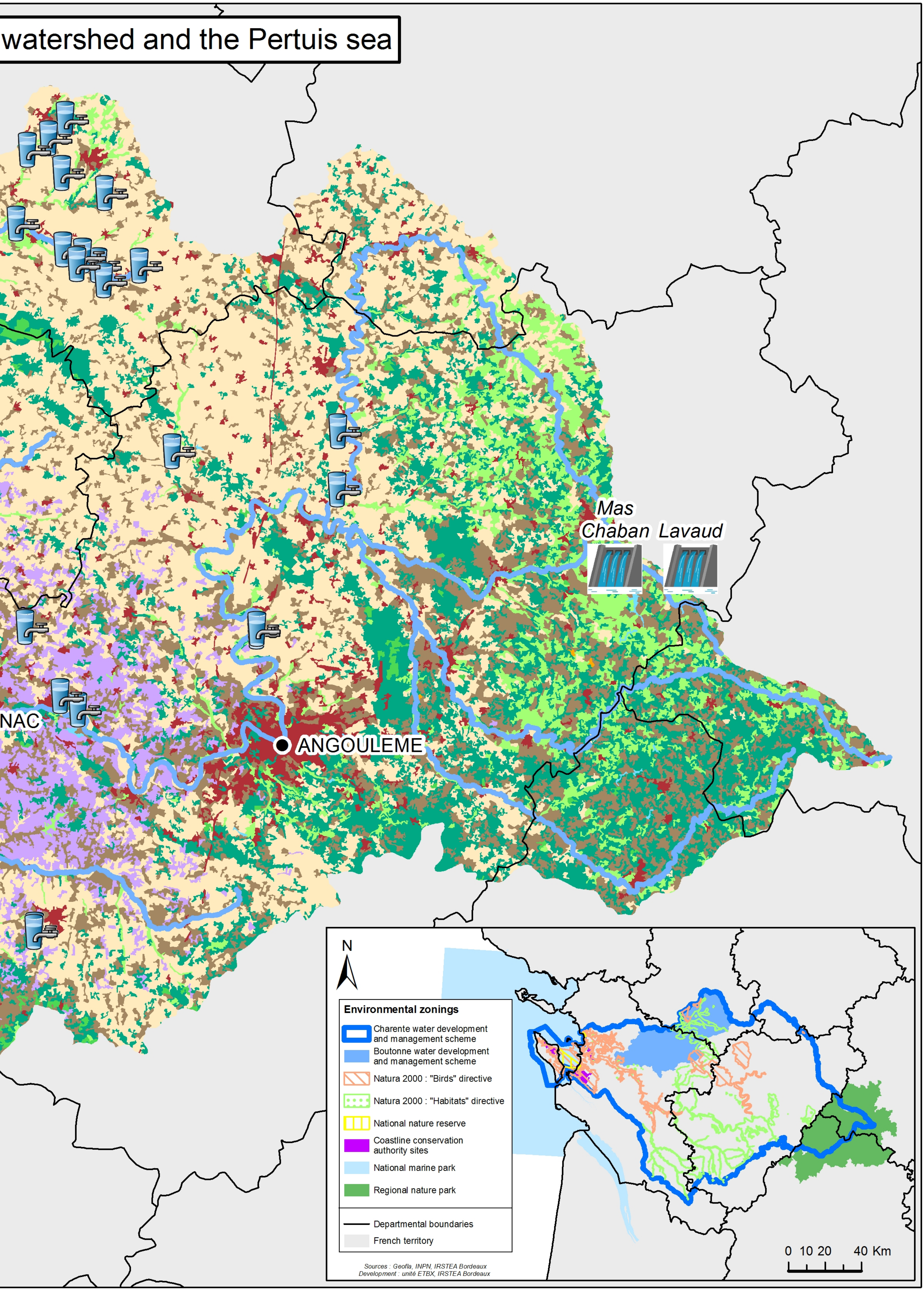


Figure 1*. Stakeholder groups involved in the workshops organised to define the scenarios for the Charente river basin and its adjecent coastal zone.*

1	Meeting with	Coastal MAL4 partners and local stakeholders
	When?	31/10/2019 and 15/11/2019
	Main goal	Two multi-actor workshops to collectively define the desirable future of the territory (global scenario, shellfish farming synergy, agriculture synergy, protection of water resources and environment).
2	Meeting with	local stakeholders
	When?	1, 14 et 15/12/2020
	Main goal	Discussions with focus groups of stakeholders (shellfish farming, agriculture, coastal partners) about the transition pathways to the desirable scenario.
3	Meeting with	local stakeholders
	When?	11/01/2020
	Main goal	Discussion with a focus group (shellfish farming and ports)
4	Meeting with	local stakeholders
	When?	19/01/2021
	Main goal	Discussion with a focus group (conventional and organic farming, water and irrigation)
5	Meeting with	MAL4 partners and stakeholders
	When?	04/02/2021
	Main goal	Multi-actor workshop with a long and interesting discussion on the business roadmap and scenarios. Several themes were discussed: agriculture, shellfish farming, water, spatial planning, infrastructure and ports.
6	Meeting with	MAL4 partners and stakeholders
	When?	10/03/2022
	Main goal	Multi-actor workshop dedicated to the validation of the dynamic model, the territorial trajectories and the business roadmap.


The study area - the Charente
N
LA ROCHELLE
LA COTINIERE
ROCHEFORT
SAINTES
COG
Landuse
Urban areas
Field crops
Vineyards
Grasslands
Heterogeneous agricultural areas
Forests
Heaths
Orchards
Beaches and dunes
Wetlands and water bodies
Marine activities
Shellfish farming areas
Infrastructures
Priority drinking water catchments
Dams
Trading ports
Fishing ports
Towns
Main rivers
Departmental boundaries
French territory
0 5 10 20 Km
Sources : Corine Land Cover, Geofla, BD TOPO
Development : unité ETBX, IRSTEA Bordeaux
irstea



watershed and the Pertuis sea
Mas
Chaban
Lavaud
NAC
ANGOULEME
N
Environmental zonings
Charente water development and management scheme
Boutonne water development and management scheme
Natura 2000 : "Birds" directive
Natura 2000 : "Habitats" directive
National nature reserve
Coastline conservation authority sites
National marine park
Regional nature park
Departmental boundaries
French territory
Sources : Geofla, INPN, IRSTEA Bordeaux
Development : unité ETBX, IRSTEA Bordeaux
0 10 20 40 Km

THE SCENARIOS IN RELATION TO THE CHARENTE SD MODEL

As the scenarios for the Charente river basin and its coastal zone deal with uncertainties external to the modelled system, they cannot be understood correctly without knowing the exact delineation of this system. What is 'in'? And what is 'out'? What is part of the modelled system? And what is not? This section therefore gives a brief introduction to the system dynamics model developed within COASTAL for the Charente river basin. Next, we given an overview of the external uncertainties studied through teh scenarios.

WHAT DID WE MODEL?

The integrated model (Figure 2) simulates, in a systemic way, the rural and coastal activities, the hydrological system and the coastal zone (the Pertuis Sea) of the Charente River basin. The upstream hinterland activities considered in the integrated model are agriculture, rural tourism, wastewater treatment and drinking water supply, while the considered downstream coastal activities are shellfish farming, coastal tourism, wastewater treatment, drinking water supply and infrastructures. The hydrological system includes different aquatic compartments (ecosystems) in the hinterland and in the coastal zone. All these activities and ecosystems interact with each other through water, both in a quantitative and qualitative way. The main processes simulated and interacting in the model are:

- the quantitative management of water resources and the maintenance/restoration of the water quality;
- the production and sale of shellfish (oysters);
- the transition of agricultural systems from a conventional to an agroecological model;
- the evolution of the residential and touristic populations, in numbers and according to their distribution over the territory;
- the development of infrastructures needed for these processes.

(More detailed information about the model structure can be found in COASTAL Deliverable 14.)

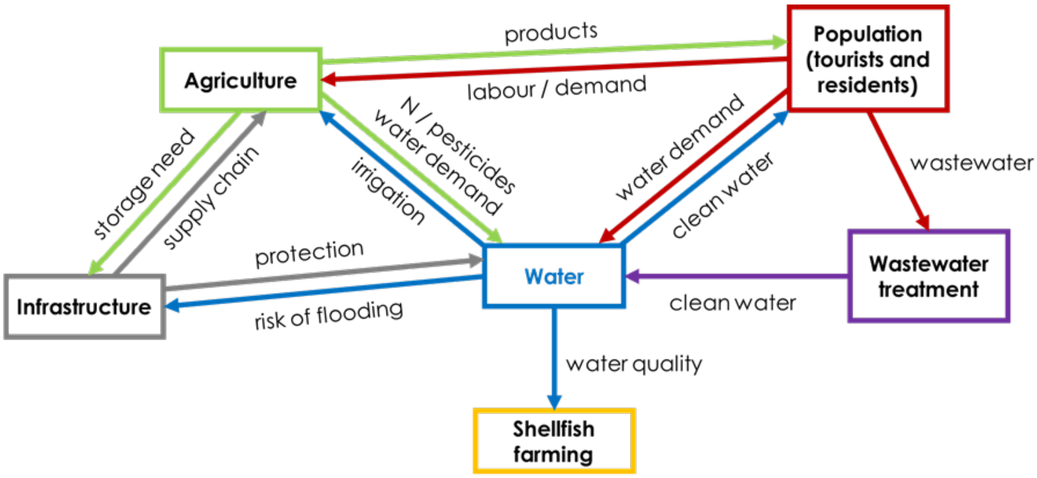


Figure 2. Structure of the integrated system dynamics (SD) model for the Charente river basin and adjecent coastal zone.

WHAT KIND OF EXTERNAL UNCERTAINTIES WERE TAKEN INTO ACCOUNT?

As explained in the introduction of this report, the Shared Socio-economic Pathways (SSPs), complemented with insights from the IPCC report "Global warming of 1.5°C" and the Representative Concentration Pathways (RCPs), were used as a starting point to develop the case-specific scenarios. In addition, the work performed in WP1 allowed us to identify the main drivers (internal and external) of the land-sea system (cfr. Table 2).

***Table 2**. Drivers of the land-sea system identified during the sectoral workshops.*

WORKSHOP	INFRASTRUCTURE	ENERGY	LIFESTYLE	POPULATION	CLIMATE	WATER	POLICIES	ENVIRONMENT	MARKET	TOTAL
AGRICULTURE / AGROINDUSTRY	4	2	9	11	17	3	22	0	13	**81**
WATER SECTOR	19	4	8	10	10	0	16	0	10	**77**
PUBLIC POLICIES / NGOs	11	2	6	14	7	1	30	12	6	**89**
SHELLFISH FARMING / FISHERIES	2	0	2	8	8	2	26	8	4	**60**
PORT / INFRASTRUCTURE / ENERGY	10	6	5	15	16	0	16	7	6	**81**
TOURISM (RURAL/COASTAL)	4	0	11	22	3	0	19	1	2	**62**
TOTAL	**50**	**14**	**41**	**80**	**61**	**6**	**129**	**28**	**41**	

Because of the large scale of our study area (10,000 km^2, encompassing several administrative areas), many drivers that might be external in smaller-scale territories, such as policies, are actually internal drivers of our system that depend on the decisions of local actors. For example, local authorities and decision makers are able to shape policies, water management plans or development strategies at the scale of our territory. Similarly, trajectories in terms of population or tourism depend on regional policies concerning infrastructures' development, spatial planning and services.

Therefore, we decided to focus on two uncertain external drivers:

- Climate, represented by two variables: rainfall and reference evapotranspiration.
- Market prices, represented by one variable: the ratio of agroecological to conventional prices for agricultural products.

Table 3 lists them together with the generic frameworks' parameters considered to explain the possible future evolution of these external drivers.

***Table 3**. Drivers of the land-sea system identified during the sectoral workshops.*

N°	Model input variable	System-external uncertainties affecting this model input variable
1	Ratio of agroecological to conventional prices	Global markets' evolution
2	Rainfall	Climate change
3	Reference evapotranspiration	Climate change

DETAILED DESCRIPTION OF THE SCENARIOS

Among the three identified external variables (cfr. previous Table 3), the two climate variables are inseparable as they are interlinked and evolve together with climate change. We thus have two main external variations to consider in the scenarios for the Charente river basin: changes in climate and changes in the prices of agricultural products.

To simulate possible future climate change - the future starts in 2020 in our model - we use the three RCP scenarios available at the scale of the Charente River basin's region (Nouvelle Aquitaine) as a starting point: RCP2.6 (+2.6 W/m^2 in radiative forcing), RCP4.5 and RCP8.5. These include data for the two climate variables of the model: rainfall and reference evapotranspiration. While the RCP scenarios provide a "realistic" picture of future climate, with extreme events and (possibly high) interannual variability, their simulation yields blurry results that can be hard to interpret, especially for variables that are very sensitive to climate. In addition, they may convey a wrong message, as they tend to represent a "positive" evolution of climate, with notably more rain in some cases. Therefore we follow two approaches for the climate scenarios:

1. We use the RCP scenarios as such, for transparency in general and in particular for users interested in observing extreme events and possible interannual variations.
2. We design, on the basis of the RCPs, smooth climate scenarios (3 for each of the two climate variables) that represent a decreasing, constant or increasing yearly rainfall or reference evapotranspiration.

The following subsection describes the climate scenarios (RCPs and smooth) and the design of the smooth ones. In the present report we look at the effect of both sets of climate scenarios. When plotting the RCP scenarios, we use RCP2.6 as a reference (line in the plots). Hence, the represented range shows the effect of RCPs increasing from 2.6 to 8.5. When plotting the smooth scenarios, we use the constant scenario as a reference (line in the plots). Hence, the represented range shows the effect of climate either increasing or decreasing. In our next report, that is COASTAL deliverable 20, we will use the smooth scenarios, which are more relevant for a general audience, and will present the results obtained with the RCPs in the annex, as they are more relevant for an expert audience. However, an exception is made for some specific KPIs that depend on extreme events (e.g. minimum water streams flow), for which we will consider the RCP results.

For the ratio of agroecological to conventional prices, we assumed three possible future levels based on the narratives of the SSPs 1, 2 and 4, as explained below.
Combining the climate scenarios and the SSPs (prices), we obtain:

1. 3 SSPs x 3 RCPs = 9 external scenarios when using the RCPs.
2. 3 SSPs x 9 combinations of 3 climate change directions for 2 variables = 27 external scenarios using the smooth climate scenarios.

The remaining part of this section describes the evolution of each variable under each scenario.

All the corresponding quantitatie data are available here: https://doi.org/10.5281/zenodo.7074942

1. VARIABLE: RATIO OF AGROECOLOGICAL TO CONVENTIONAL PRICES

For simplification purposes, we chose not to define the potential evolution of prices per crop (a complex endeavor), but instead the ratio of agroecological prices to conventional ones. Note that although this variable is present in the model, it is not directly used there. Instead, we used it to calculate future prices for the different conventional and agroecological cultures considered in the model (see also COASTAL deliverable n° 14 "Operational SD Models for Coastal-Rural Interactions" provides further explanations").

Scenario 1 (SSP1)

As agroecology becomes widespread in this scenario, the price ratio should decrease to the point where prices are almost equal. We thus set the ratio at 1. In reality, it should remain a bit higher, but stakeholders pointed out that it would be interesting to look at the effect of equal prices.

Scenario 2 (SSP2)

In this scenario, agroecology develops but not to the point where prices converge with conventional ones. Therefore, we set the price ratio at 1.5 (lower than the current ratio of 2).

Scenario 3 (SSP4)

In this scenario, agroecology remains a niche and so agroecological products are still scarcer and more expensive. Hence, the price ratio stays at 2.

These values are final ones for the year 2050. To depict the evolution of the ratio over time, we assumed a simple linear increase or decrease (cfr. Figure 3).

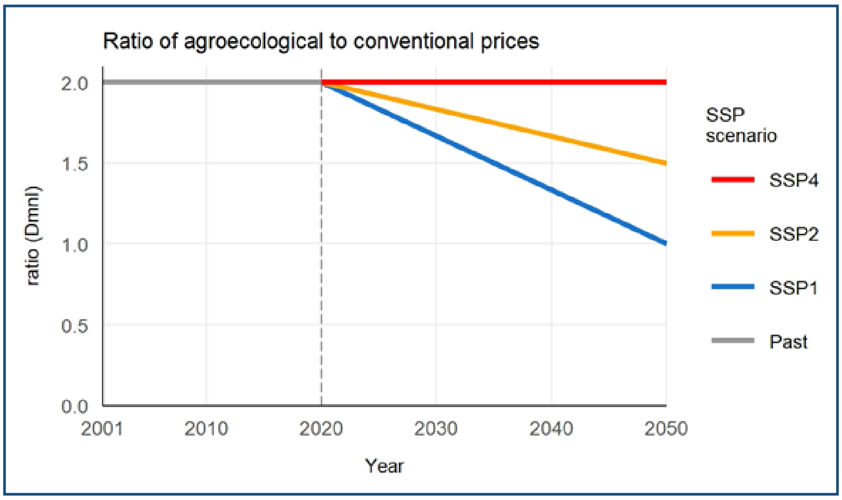


Figure 3. *Evolution of the ratio of agroecological to conventional prices under the different scenarios.*

2. VARIABLES RAINFALL & REFERENCE EVAPOTRANSPIRATION

Figure 4 and Figure 5 show the evolution of rainfall (in mm/month) and reference evapotranspiration (ET_0, in mm/month) in each RCP scenario. Differences between RCP scenarios are more obvious in peak events and seasonality.

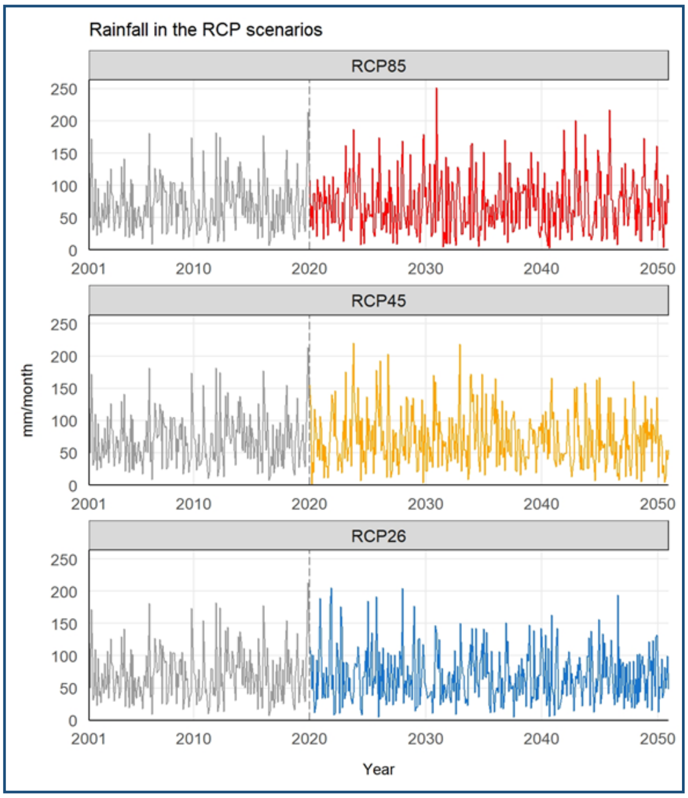


Figure 4. Rainfall under each of the Representative Concentration Pathways (RCPs).

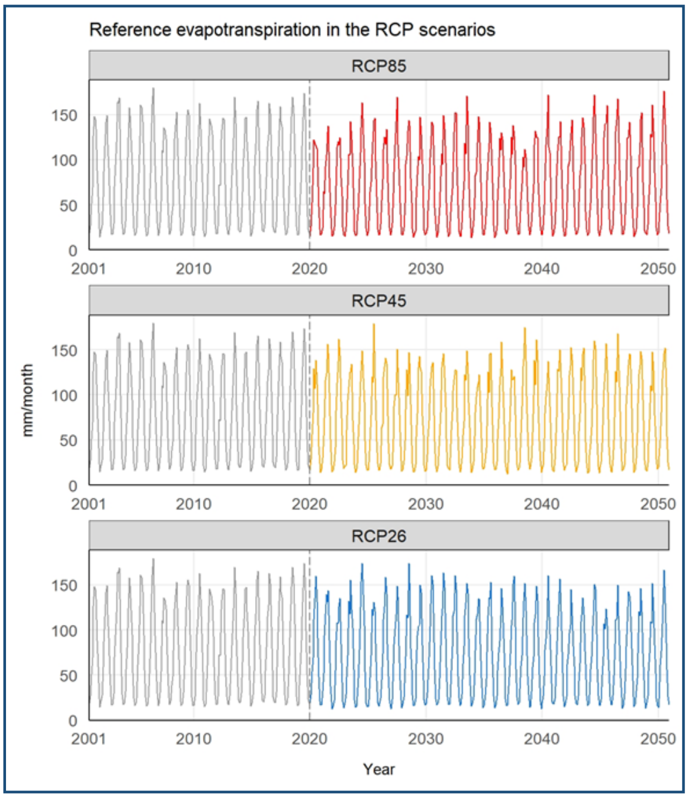


Figure 5. Reference evapotranspiration under each of the Representative Concentration Pathways (RCPs).

As can be seen in Figure 6, according to the RCPs yearly rainfall should slightly increase in the region with radiative forcing. On average, it should not reach much higher levels than in the past, but interannual variability should be higher, with dryer and wetter extremes.

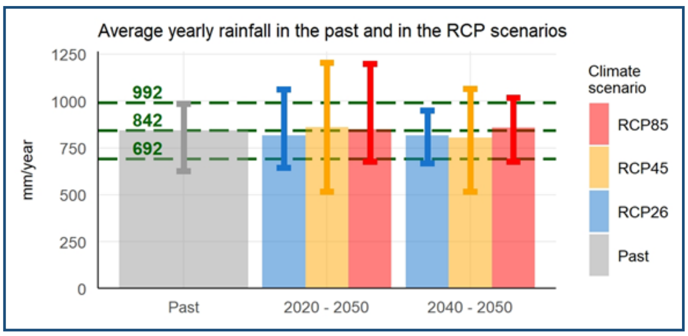


Figure 6. Average yearly rainfall in the past and in the RCP scenarios. The error bars show the min-max range over each period. The green dashed lines show the values reached by 2050 in the smooth climate scenarios.

Concerning yearly reference evapotranspiration, Figure 7 shows that also this variable should increase with radiative forcing. Though, in general, it should decrease when compared to the past. This second aspect is a bit counterintuitive. Given that this decrease in yearly ET_0 is instantaneous in the RCP scenarios (yearly ET_0 is ~980 mm/year in 2019 and ~850 in 2020), this overall suggests an issue in the underlying model. While we use these scenarios as such, we "correct" this issue when designing our smooth scenarios, as explained below.

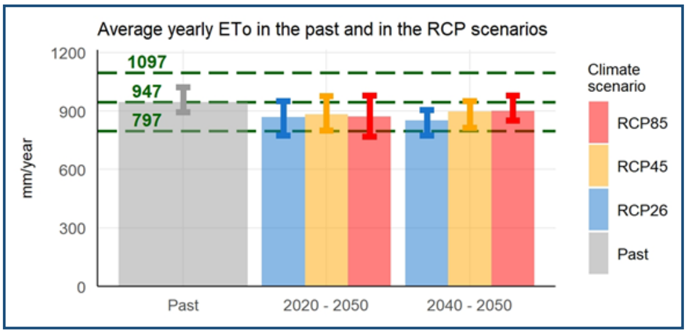


***Figure 7**. Average yearly reference evapotranspiration (ET_0) in the past and in the RCP scenarios. The error bars show the min-max range over each period. The green dashed lines show the values reached by 2050 in the smooth climate scenarios.*

To design the smooth scenarios, we followed the same procedure for rainfall and evapotranspiration:

1. We chose a final yearly value reached by 2050. For each variable we considered three cases: a decreasing, constant or increasing yearly total. These values are indicated in Figure 6 and Figure 7. For the constant case, we used the past average. For the decrease and increase, we considered the same absolute change. In the case of rainfall, we chose this absolute change so that it approximates the RCP scenarios' extreme cases during the 10 last simulated years. In the case of reference evapotranspiration, the RCP scenarios appear as a less reliable basis, as explained previously. We thus chose the absolute change (+/- 150 mm/year) according to past data, doubling the maximum absolute difference with the average observed in the past (+75 mm/year when compared to average in 2003). Once we set all these final values, we calculated time series of yearly rainfall and reference evapotranspiration for each direction of change, while assuming a linear evolution over time.
2. In addition, we considered how the distribution over a year of rainfall and reference evapotranspiration should evolve over time. As shown in Figure 8, which presents rainfall projections, summers should become drier while the rest of the year will become wetter, apart from early spring. For reference evapotranspiration, its yearly distribution should change less significantly, with a lower ET_0 in June and a higher one in August. On the basis of these data, we calculated time series of yearly distribution for rainfall and reference evapotranspiration, assuming a linear evolution of this distribution from the past average shape to the RCPs' average shape, as illustrated in Figure 9.
3. Multiplying, for each variable, each yearly total time series (3 directions) by the yearly distribution time series, we obtained the smooth scenarios time series presented in Figure 10 for rainfall and Figure 11 for reference evapotranspiration.
4. Ultimately, we crossed the 3 scenarios obtained for each variable (e.g. we put together a decreasing rainfall with a constant reference evapotranspiration) to get the 9 smooth climate scenarios used for simulating the possible range of future climate change in the model.

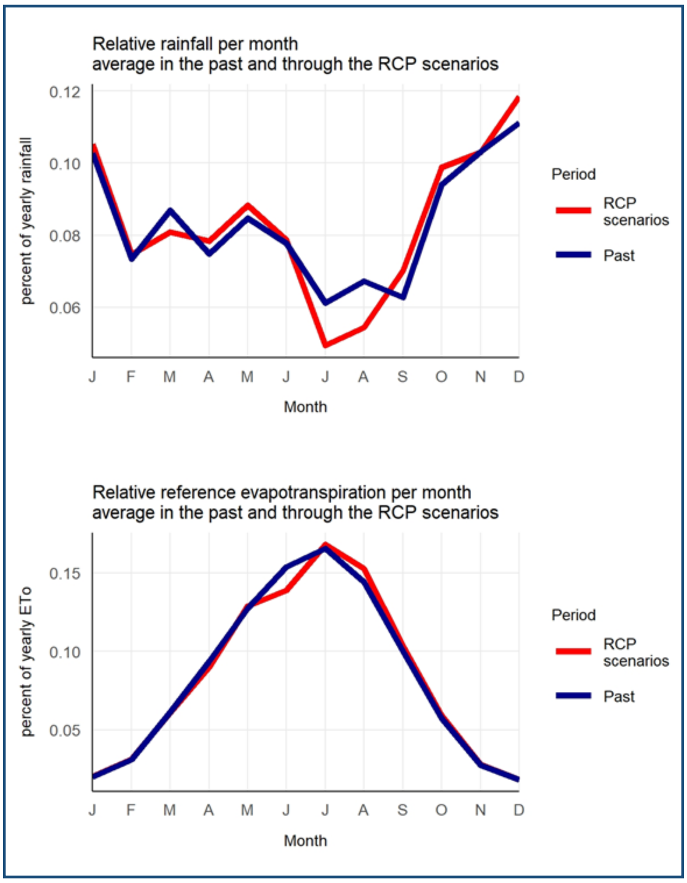


Figure 8. Relative rainfall and reference evapotranspiration per month (monthly share of the yearly total), averaged in the past and through the RCP scenarios.

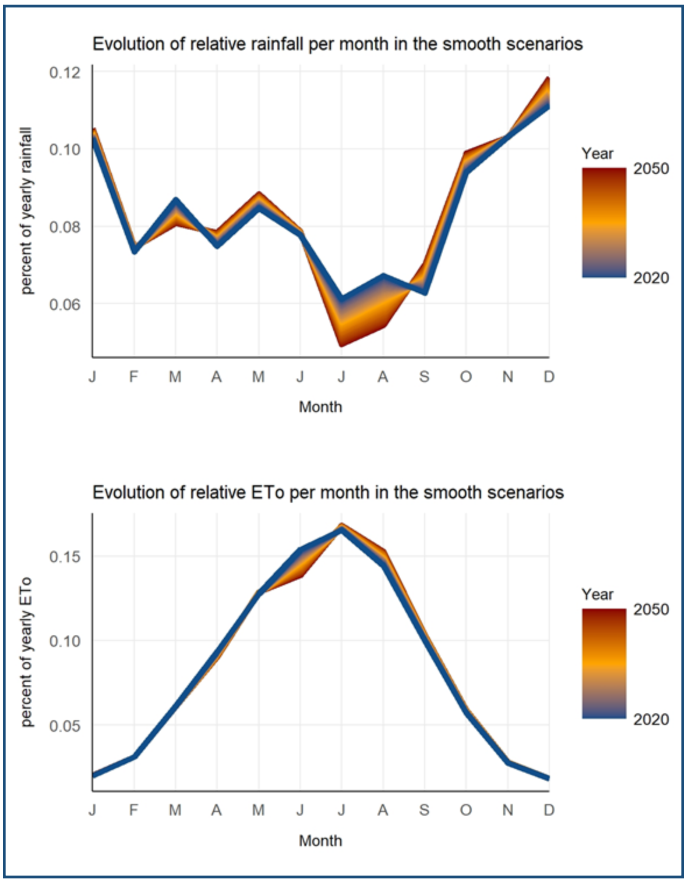


Figure 9. Evolution over time of relative rainfall and reference evaporation (ET_0) per month (monthly share of the yearly total) in the smooth climate scenarios.

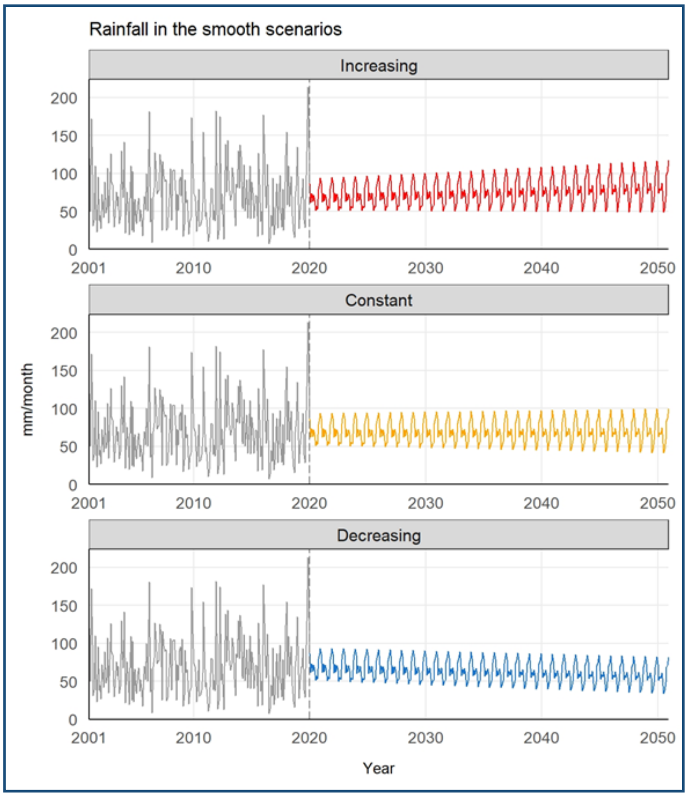


Figure 10. Rainfall in the designed smooth climate scenarios.

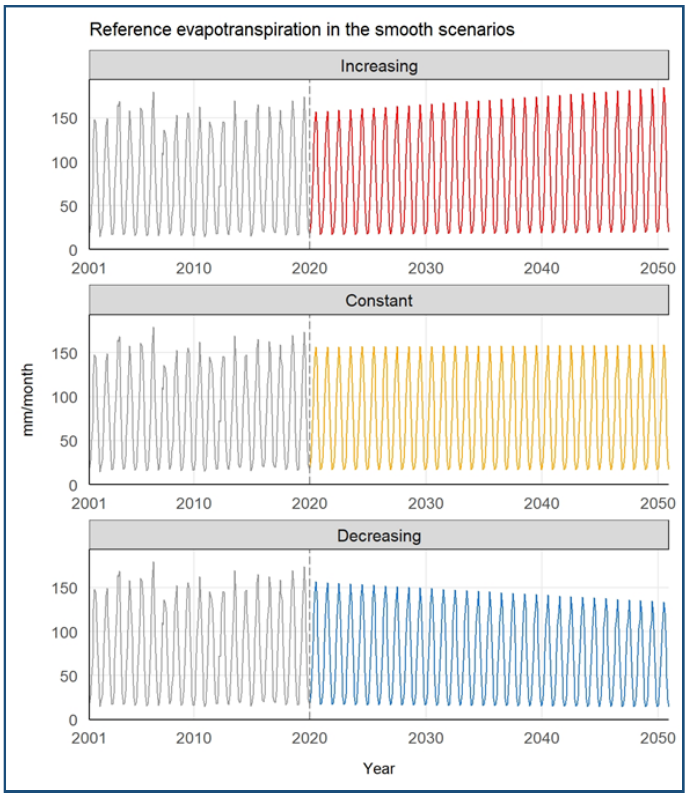


Figure 11. Reference evapotranspiration in the designed smooth climate scenarios.

COMPARISON OF THE DYNAMIC PATTERNS OF KEY MODEL VARIABLES

In this section we investigate the impact of the external uncertainties represented in the scenarios on some key variables (KPIs) of the model. When doing so, the model's input variables other than the external ones (rainfall, reference evapotranspiration and agricultural prices) are set in order to represent the current trends of the territory's development. In other words, we look at the effect of external uncertainties assuming a "business-as-usual" evolution of the Charente River basin.

Table 4 lists the KPIs considered in our study. They were selected together with the consulted stakeholders. Note that in the present report we do not consider the population and infrastructure development KPIs included in the model, because they are not sensitive to climate or agricultural prices in the current design of the model. Also noticable is that we interpret the evolution of some KPIs related to agriculture, since they are directly correlated to the agroecological share of the UAA. Hence, as we will see, they are similarly sensitive to external scenarios.

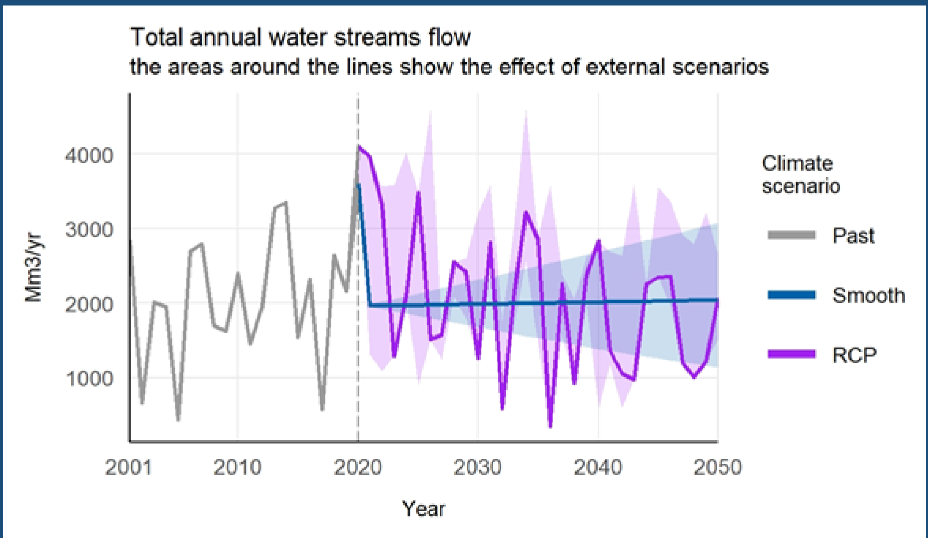
Table 4*. Key policy indicators (KPIs) for the Charente River basin. The colours correspond with the sectors of activity: blue for water management, yellow for shellfish farming, green for agriculture, pink for population and tourism, and grey for infrastructure. The grayed KPIs are not considered in the present report.*

KPI	Description	SD model variables
Water streams flow	The water streams flow, considered here at the most downstream measuring station in Beillant, must be over a certain threshold (low-water target flow) needed for the good functioning of aquatic ecosystems and for the sustainability of the resource. It is constantly monitored and restrictions on water use, notably for irrigation, are triggered when it is below the threshold.	water streams flow
Water use	Water use is a main driver of water depletion with climate change.	total water use irrigation water use domestic water use industrial water use
Water deficit	The agricultural actors identified the availability of water for irrigation as a limiting factor of their production, as well as a driver of changes in practices. The availability of water for domestic uses has to be guaranteed.	irrigation water deficit domestic water deficit
Oysters production performance	The performance of oysters production is assessed with three indicators: The **quality index** of an oyster is equal to the ratio of its flesh weight to its total weight. Oyster farmers aim to increase this ratio since rich in flesh oysters are more demanded and sold at a higher price. **Total sales**, which depend in part on the quality of oysters, are quantified in tons. The sustainable transition of the territory should at least maintain, if not improve, economic development, measured here through **gross margin**.	oysters quality index total sales oysters gross margin of shellfish farming
Spats capture	Oyster farmers know the quantity of spats that they have to capture to meet production targets. The spats that cannot be captured are purchased in nurseries. The objective of farmers, notably small-scale ones, is to capture as many spats as possible because they can be labelled (local production). Still, the purchase of spats is to some extent always necessary in order to cope with high mortality episodes.	spats capture

KPI	Description	SD model variables
Employment in shellfish farming	The sustainable transition of the territory should at least maintain, if not improve, economic development, measured here through employment.	employment in shellfish farming
Share of the UAA under agroecological farming	Agricultural policies aim to foster a more sustainable agriculture, represented here by agroecological systems. In this sense, increasing the share of the UAA under agroecological farming is a target of the territory's desired development.	share of the UAA under agroeco-logical farming
Agricultural inputs	Uses of nitrogen and pesticides are indicators of pressure on water quality. They are considered as indirect proxies of water quality.	nitrogen use agriculture pesticides use agriculture
Agricultural yields	The transition towards less intensive agroecological practices will necessarily diminish yields. While this trade-off has to be accepted and accompanied by a change in consumption, yields should not diminish too much in order to maintain local food production capacities.	[cereals/oleaginous/ proteaginous] yield animal husbandry capacity
Composition of agricultural production	The transition to more sustainable farming systems should also aim for a more diversified production, supporting a healthier and less impacting diet. Meat production is also meant to transit towards less intensive systems producing less (reduced part in diets) but of higher quality (healthier).	[cereals/oleaginous/ proteaginous] yield [conventional/ agroecological] animal husbandry capacity [con-ventional/ agroecological]
Gross margin of agriculture	The sustainable transition of the territory should at least maintain, if not improve, economic development, measured here through gross margin.	gross margin of agriculture
Employment in agriculture	The sustainable transition of the territory should at least maintain, if not improve, economic development, measured here through employment.	employment in agriculture
Population	The evolution of the residential population and of touristic affluence are important indicators for the local authorities who have to adapt their policies to demography. Their distribution between the coastal and rural areas is also tracked, with the aim to have a more harmonious distribution that will diminish pressures in the saturated coastal zone and will foster the development of the rural area.	total population coastal residents coastal tourists rural residents rural tourists
Infrastructure development	The development of infrastructures supporting the functioning of the territory will be necessary. Land artificialization should however be as low as possible in order to preserve ecosystems and ecological continuities. The necessary adaptation of infrastructure will also have a cost that diverse actors will have to assume in order to support the territory's sustainable development.	total area of infrastructure total investments for infrastructure
Attractiveness of the territory	The ability of the territory to offer actors the conditions that convince them to locate their projects on the territory rather than on another. It depends on multiple social, economic and environmental factors.	attractiveness of the territory

KPI 1: WATER STREAMS FLOW

Figure 12 shows that the yearly total and the yearly minimum of the water streams flow are sensitive to external scenarios, mostly to climate change in fact, which seems logical. Considering the RCP scenarios, they should know more drastic extremes than in the past. Looking at the yearly total, we can see that the range obtained with the smooth scenarios is an acceptable approximation of the one obtained with the RCPs, especially in the last simulated years. However, this is not the case for the minimum. Therefore, we will always consider the RCP scenarios when looking at this variable.



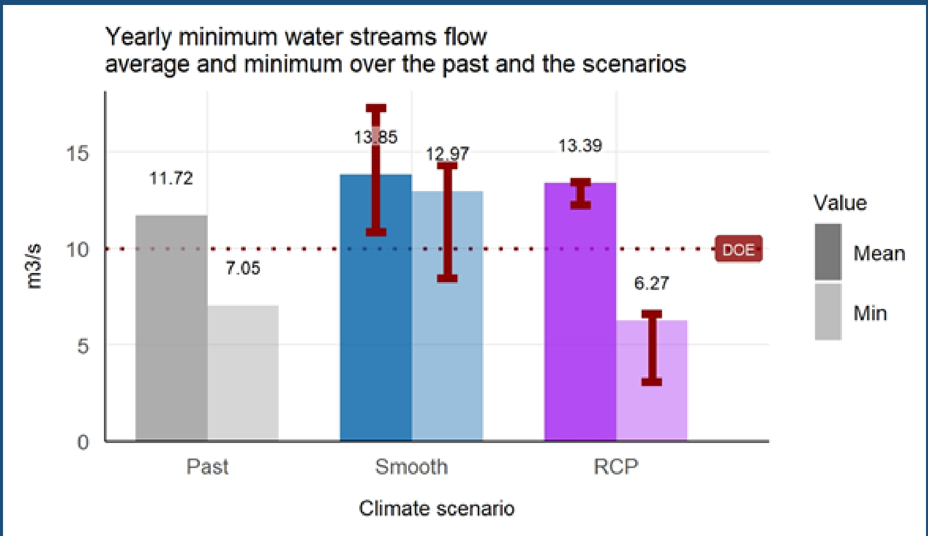
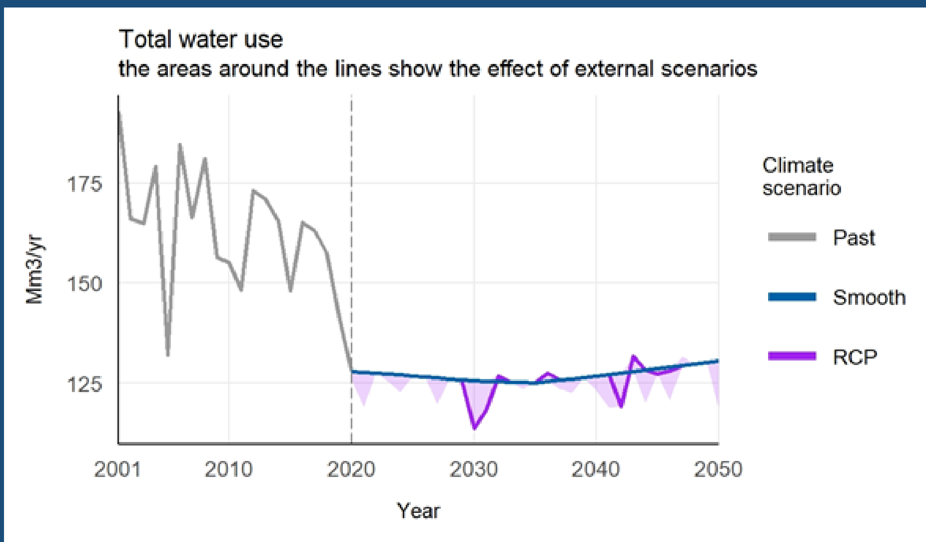


***Figure 12**: Effect of external scenarios (climate and prices) on the water streams flow (top: yearly total, bottom: yearly minimum) under a business-as-usual scenario. The red error bars show the range due to varying future climate change. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

KPI 2: WATER USE

Water use is not very sensitive to external scenarios - only under the RCP climate scenarios (cfr. Figure 13). This means that water use is affected only during extreme years. In fact, only water use for irrigation is sensitive, which is explained by the design of the model where domestic and industrial uses have priority. Because agroecology, which demands less irrigation, keeps increasing along our business-as-usual scenario, and because the abstraction permits for irrigation have diminished a lot in the past years and should remain low in the future (hence the lower water use than in the past), irrigation water demand should be more easily met in the future. This also explains why water use is not very sensitive to climate change.



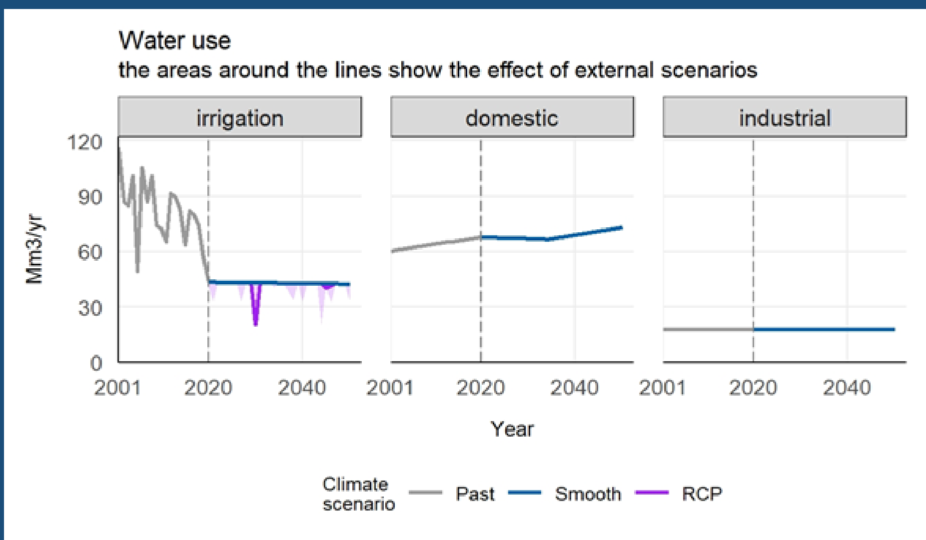


***Figure 13**: Effect of external scenarios (climate and prices) on water use (top: total, bottom: per use) under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

KPI 3: WATER DEFICIT

A first result here, is that no deficit has been observed and should occur for domestic uses under the business-as-usual scenario. For irrigation (cfr. Figure 14), deficits occur mostly under the RCP climate scenarios. Unfortunately, with a potential yearly recurrence pattern, depending on how drastic climate change will be. Under the smooth scenarios, deficits appear only under the worst scenario (decreasing rainfall and increasing evapotranspiration) and in the last years. That is because under the smooth scenarios, the water streams flow remains at a sufficient level to meet the diminishing demand for irrigation water. Therefore, we will always consider the RCP scenarios when looking at this KPI - similar to what we will do for the minimum water streams flow (first KPI).

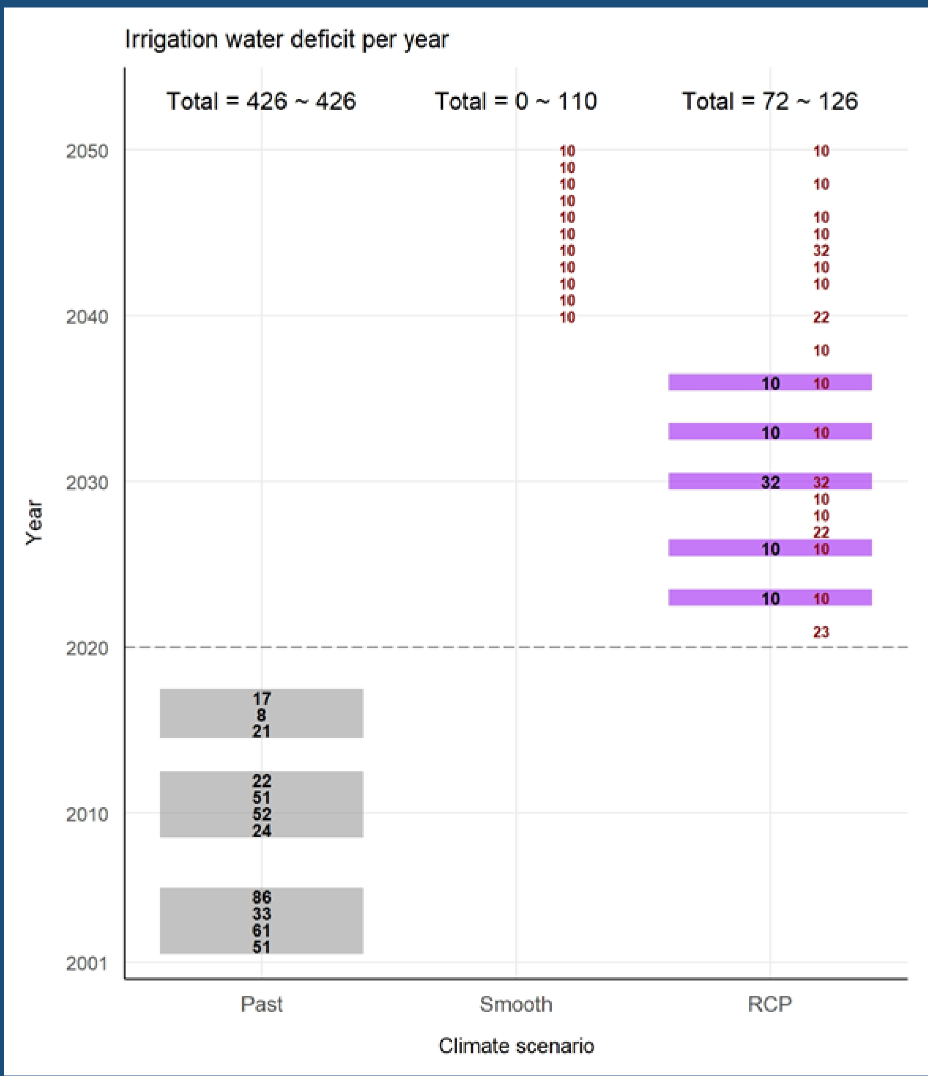


***Figure 14**: Effect of external scenarios (climate and prices) on irrigation water deficit under a business-as-usual scenario. The figure shows, in black, the yearly deficit under the reference climate scenario ("Constant" smooth or RCP2.6), and in red, the maximum deficit through the other climate scenarios. Future climate change is simulated with RCP scenarios or smooth designed ones.*

KPI 4: OYSTERS PRODUCTION PERFORMANCE

Oyster quality (cfr. Figure 15) is very sensitive to climate change, which is logical since it is directly impacted by water flows carrying trophic resources. Again, the smooth scenarios appear to be an acceptable approximation of the RCP ones. As a result of oysters' quality being sensitive, the same can be said about the sales and gross margin of shellfish farming (cfr. Figure 16). In the case of sales, note that they seem to reach a maximum for certain years under the RCP scenarios and all the time under the best smooth climate scenario (top of the drawn area). That is when all the produced oysters are sold because they have a high enough quality, which is the preferable situation for shellfish farmers.

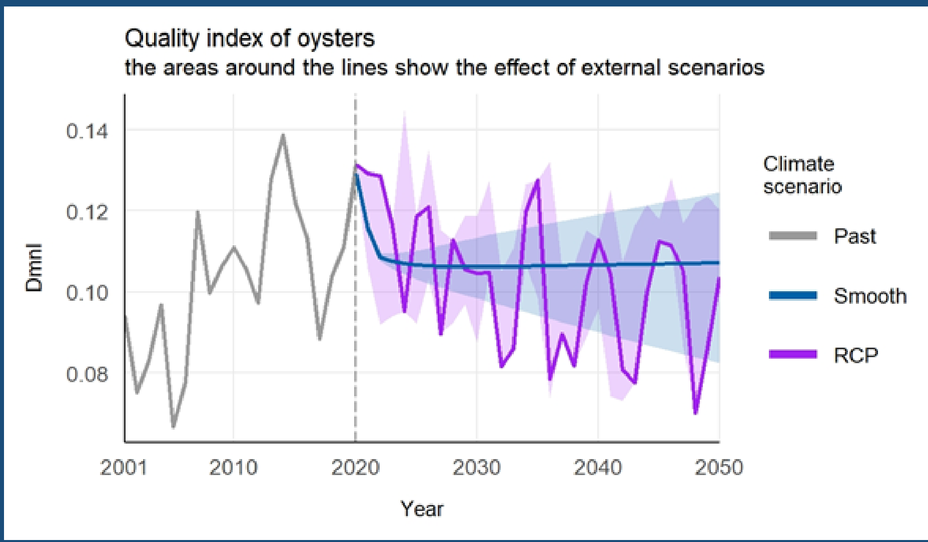


***Figure 15**: Effect of external scenarios (climate and prices) on the quality of oysters under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

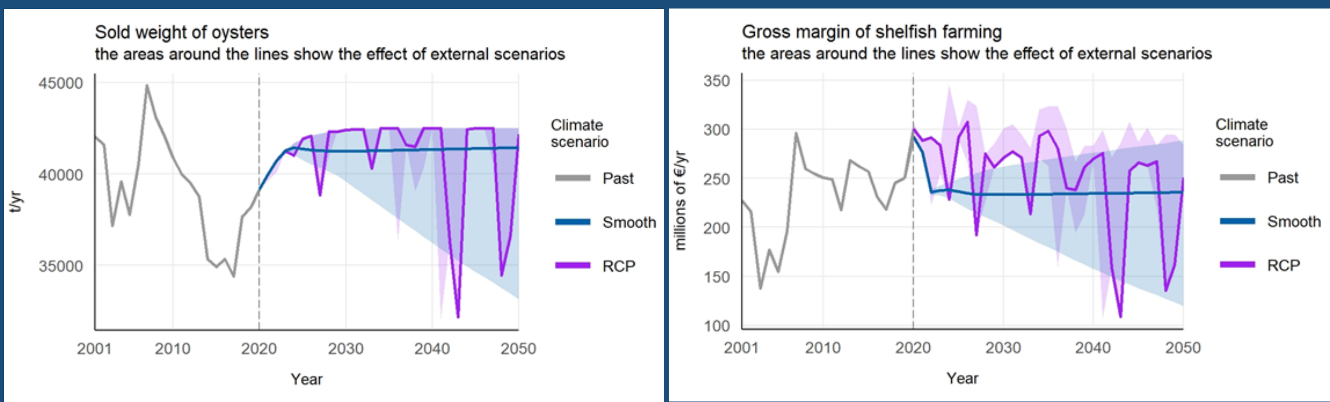


***Figure 16**: Effect of external scenarios (climate and prices) on the sales of oysters and on the gross margin of shellfish farming under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

KPI 5: SPATS CAPTURE

The capture of spats, like the quality of oysters, depends directly on the water flows and the trophic resources in them. Therefore, it is sensitive to climate change (cfr. Figure 17). Yet, it should not reach much lower levels than in the past under the business-as-usual scenario and all climate scenarios. However, being careful, we note that data on this topic are scarce and so the magnitude of the effect simulated with the model may be incorrect (most likely underestimated).

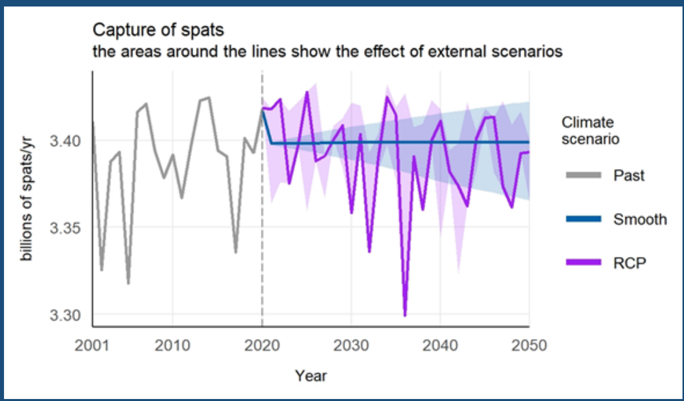


***Figure 17**: Effect of external scenarios (climate and prices) on the capture of spats under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

KPI 6: EMPLOYMENT IN SHELLFISH FARMING

Because employment in shellfish farming depends on the produced quantity and not the quality of the production or the sales, it is not sensitive to climate change, as shown in Figure 18 below.

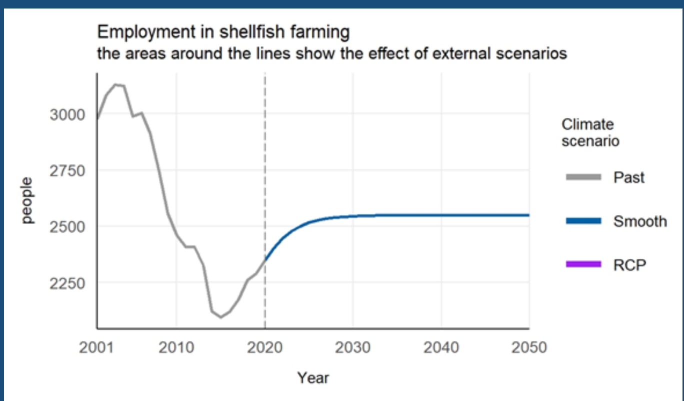


***Figure 18**: Impact of the external scenarios (climate and prices) on employment in the shellfish farming industry under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

KPI 7: AGRICULTURAL YIELDS

As illustrated in Figure 19, agricultural yields are not very sensitive to external scenarios. Climate change is the most relevant external driver here, which is in line with our previous observations on water use and the irrigation water deficit. In fact, they are most affected when the water flows reach a too low level, that is below the regulatory limit, and the irrigation demand cannot be fully met. This occurs during extreme years in the RCPs or at the end of the smooth scenarios.

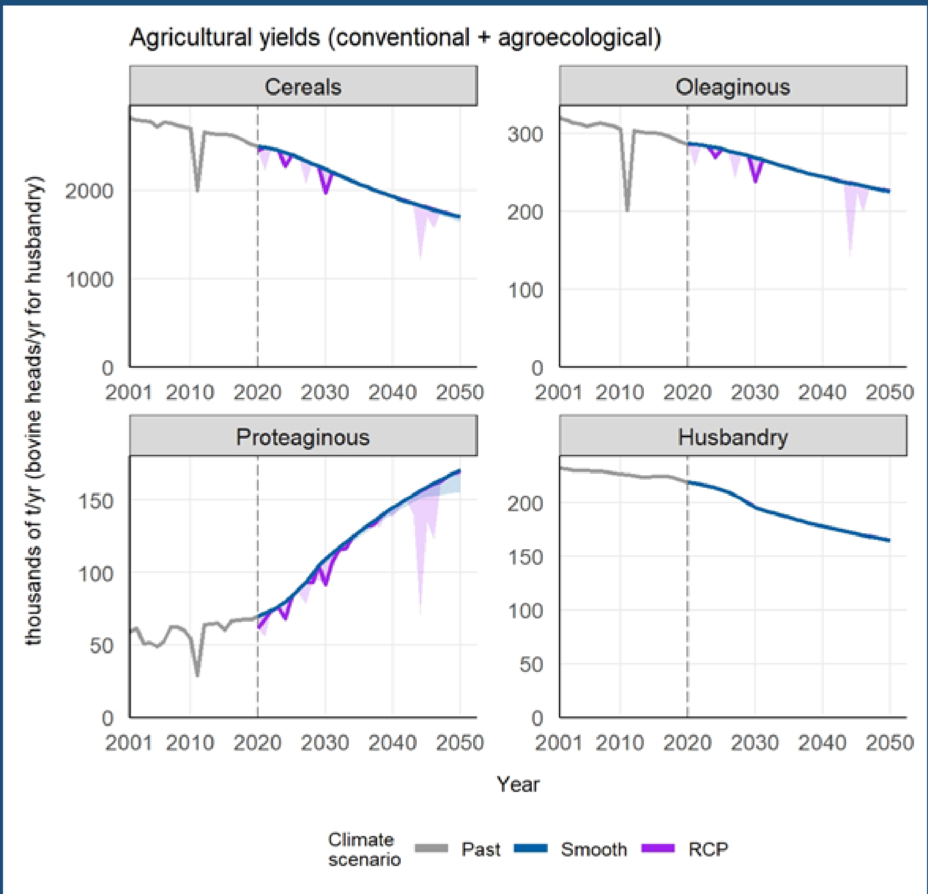


Figure 19*: Effect of external scenarios (climate and prices) on agricultural yields under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

KPI 8: SHARE OF THE UAA UNDER AGROECOLOGICAL FARMING

In the design of the model, the conversion of agriculture towards an agroecological model does not depend much on climatic conditions (there is a very thin area around the line in Figure 20). We choose to consider this conversion as a mostly anthropogenic phenomenon, although there still is a small part affected by environmental constraints in the model. This decision was based on expert opinions, notably farmers themselves and consumers. We did so to be in line with most of the stakeholders' points of view, who think that the territory should be pro-active on this conversion and should not wait until too strong environmental constraints emerge. Prices influence the conversion too, but not a lot. Although the ratio of agroecological to conventional prices diminishes through the external scenarios, the difference in income between agroecology and conventional farming remains high because agroecological yields are more maximized than conventional ones in the future where less water is used/available. The use of agricultural inputs (nitrogen in Figure 21 and pesticides, not depicted) and employment in agriculture (Figure 21), which directly depend on the agroecological share of the UAA, are also not sensitive to climatic changes.

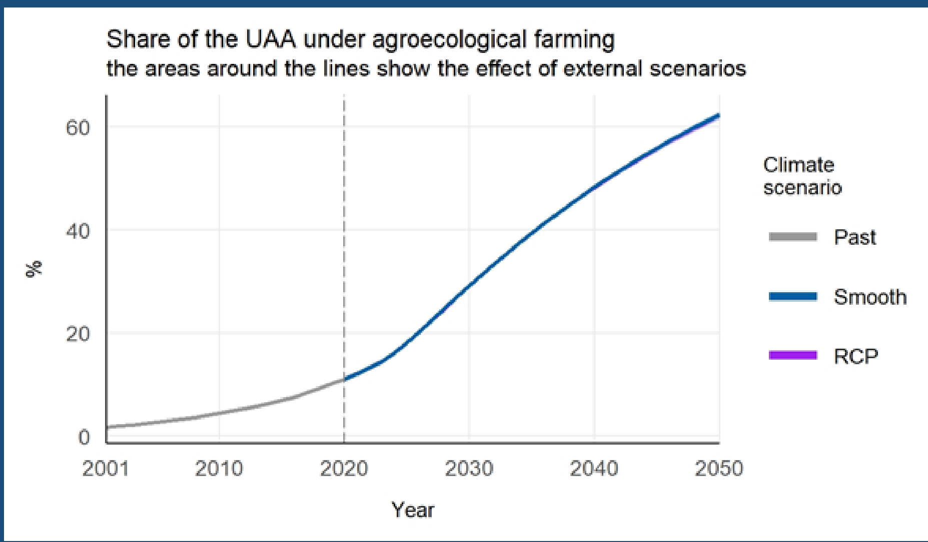


***Figure 20**: Effect of external scenarios (climate and prices) on the agroecological share of the UAA under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

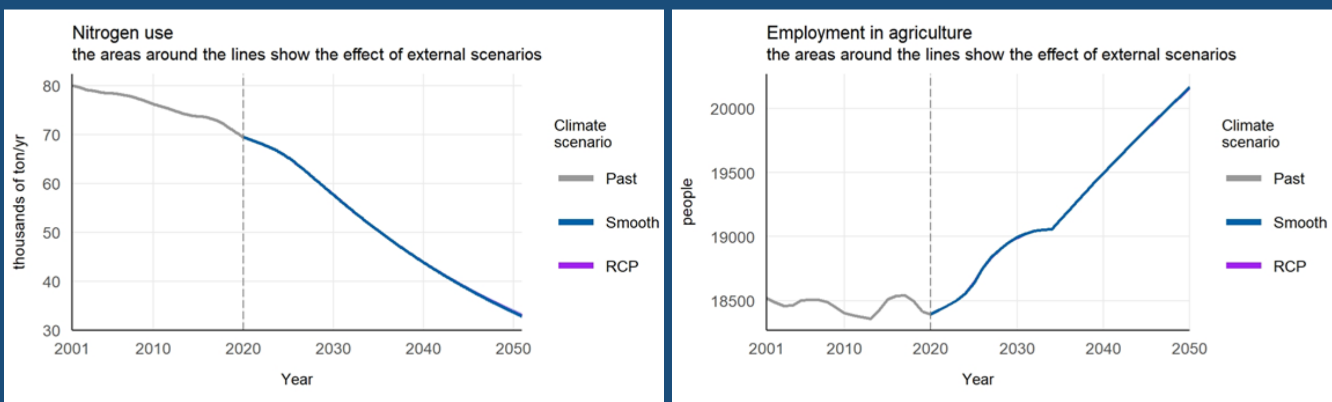


***Figure 21**: Effect of external scenarios (climate and prices) on nitrogen use (top) and employment in agriculture (bottom) under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

KPI 9: GROSS MARGIN OF AGRICULTURE

The gross margin of agriculture is very sensitive to external scenarios (cfr. Figure 22). It is sensitive to both climate change (a little) and agricultural prices (a lot). Looking at the shape of the areas in Figure 22, the common central part is in fact due to changes in the price ratio, while the peaks, which correspond to the peaks in Figure 19, are due to changes in yields (i.e. climate).

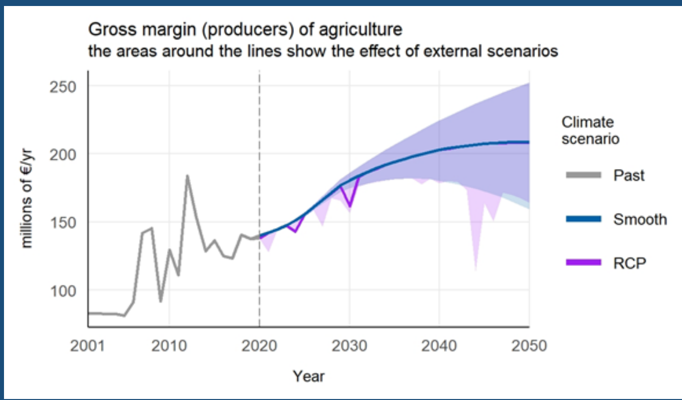


***Figure 22**: Effect of external scenarios (climate and prices) on the gross margin of agriculture under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

KPI 10: ATTRACTIVENESS OF THE TERRITORY

As a summary of the previous KPIs, the attractiveness of the territory is quite sensitive to external scenarios (it is a mix of very sensitive and not sensitive indicators). Given the previous results, we can logically say that the more directly linked to a natural phenomenon is a KPI, the more sensitive it is to climate change. Hence, to ensure the attractiveness of the territory and make it more resilient to climate change, efforts should focus on improving the resilience of the previously identified most sensitive activities.

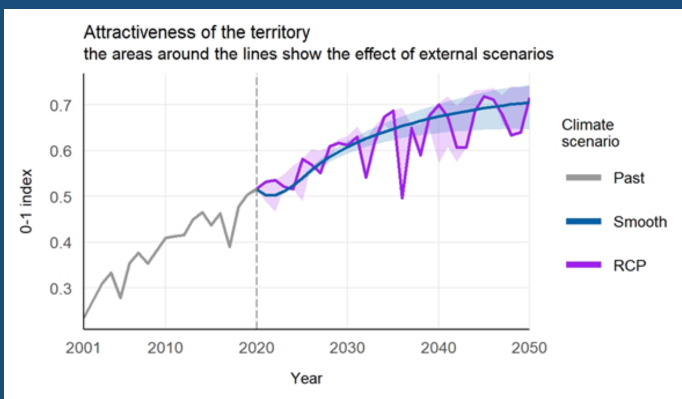


***Figure 23**: Effect of external scenarios (climate and prices) on the attractiveness of the territory under a business-as-usual scenario. Future climate change is simulated with RCP scenarios (reference: RCP2.6) or smooth designed ones (reference: constant scenario).*

SCENARIOS FOR THE DANUBE'S MOUTHS - BLACK SEA REGION

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COASTAL
Collaborative Land-Sea Integration Platform

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CONTEXTUAL ELEMENTS INFLUENCING SCENARIO BUILDING

The Danube's Mouth and adjacent Black Sea area is part of the Danube Delta Biosphere Reserve. The goal of our model is to explore alternative scenarios of human activities development with the improvement of the quality of life and sustainability within the Danube Delta Biosphere Reserve and its marine waters (Black Sea), as one of the most impacted areas along the Romanian littoral. Therefore, the Romanian model is organized from a threefold perspective, that integrates the main economic activities in the region, namely, aquaculture, tourism, and agriculture. Each of these three sub-models feeds into a master file addressing the socio-economic development of the area expressed as the rural income. As a consequence; two local organizations (actors) are involved in sub-model development – LAG Dobrogea Centrala and LAG Delta Dunarii. In addition to this also - ITI (Integrated Territorial Investment) Delta Dunarii Intercommunity Development Association which implements the ITI mechanism in the area was involved from the project's very beginning.

The aquaculture sub-model may serve the area's sustainable development in the future by predicting the beneficial effects of the onset of such economic activity, while also pointing out the possible side effects that should be considered, with the final goal to help the decision-making actors properly design a development strategy for the sector. The rural tourism sub-model intends to answer the question of what level the tourism can be developed in the interested area without harming the environment. Finally, the agriculture model's central point is the potential environmental impact of the increasing conversion rate of conventional agriculture to organic farming.

STAKEHOLDER INVOLVEMENT DURING THE SCENARIO BUILDING PROCESS

PROJECT PARTNERS

During the coordinated workshops, two local actors, a non-profit association, namely Local Action Group Dobrogea Central, and LAG Delta Dunarii were actively involved in bringing stakeholders to meetings. Representatives of the following organizations gave input for the scenarios:

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Local Action Group Dobrogea Centrala (COASTAL actor partner)	Non-profit organisation	Rural development	2	1	1	
Local Action Group Delta Dunarii (COASTAL actor partner)	Non-profit organisation	Rural development	2	1	1	

OTHER STAKEHOLDERS

To have stakeholders from various fields of interest, the COASTAL workshops also invited representatives of the following organizations or institutions:

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
ANPA (Romanian Agency for Fishery and Aquacul-ture)	Governmental	Reglemantation	1		1	
RO-PESCADOR	Association	Representation	1	1		
ITI Delta Dunarii	NGO	Representation	1		1	
Ministry of Agriculture and Rural Development	Administration	Rural Development	2	1	1	
University of Agronomic Sciences and Veterinary Medicine of Bucharest	University	Rural Development	1	1		
The Academy of Agricultural and Forestry Sciences Gheorghe Sisesti	Academy	Rural Development	1	1		
The Bucharest University of Economic Studies	University	Rural Development	1	1		
Romanian Association for Sustainable Agriculture	NGO	Agriculture, Rural Development	2	2		
National Association of Agricultural Cooperatives in Romania	NGO	Agriculture, Rural Development	1	1		
City hall Ciocârlia	Local, public administration	Agriculture, Rural Development	2	1	1	
City hall Topalu	Local, public administration	Rural tourism, Rural development	1	1		
Farmer’s association	NGO	Agriculture	1		1	
Independent small business representatives	Local economic agents	Tourism	6	4	2	

RATIONALE STAKEHOLDER SELECTION

Stakeholders were chosen to participate due to their experience in the theme discussed, with a focus on the land-sea interactions, and their interest in the COASTAL project results.

SCENARIO DEVELOPMENT APPROACH

From the first COASTAL meetings on, we wanted to get as close as possible to the stakeholder's vision on the area of interest, the Danube Delta. Therefore we asked them what should change over time for their activity to improve. With their ideas, we started to draw scenarios, and to see the evolution of the variables linked to these scenarios, we used modelling activity. Due to the pandemic restrictions, part of this development process was done through online meetings, phone calls or e-mail. Apart from the desk research, we also travelled through the territory to understand in-depth the stakeholders' vision. It was interesting to assess the situation from a researchers' perspective (our perspective) and to complement these insights with the image inhabitants have of the future of their area.

Taken everything together, scenario development started with the workshop organized in September 2019, which was attended by representative stakeholders of both the rural area and the coastal zone. Other meetings about scenarios development were held in March 2021 and December 2021.

***Table 1**. Overview of the main meetings in the scenario development process.*

1	Meeting with	Stakeholders
	When?	September 2019
	Main goal	To validate the pilot models and discuss possible scenarios and future narratives for the area.
2	Meeting with	FLAG Delta Dunarii
	When?	16 March 2021
	Main goal	To discuss the area's features and particular variables of the Aquaculture sub-models.
3	Meeting with	Stakeholders
	When?	9 March 2021 - online
	Main goal	To validate the developed models and discuss possible improvements and scenarios for the Vensim models.
4	Meeting with	IDA ITI Danube Delta + Local Action Group Delta Dunarii
	When?	13 December 2021
	Main goal	We discussed the main scenarios designed for fish farming, rural tourism and agriculture focusing on how our approach fits with the perspective of the stakeholders involved.
5	Meeting with	Local Action Group Dobrogea Centrala
	When?	17 December 2021
	Main goal	The main topics covered were fish farming, agriculture, and tourism and the developing possibilities of these sectors in the case study area. In addition to this, we also wanted to give the participants the opportunity to validate the outlined scenarios.

ESA - Earth from space: Danube Delta

THE SCENARIOS IN RELATION TO THE SYSTEM DYNAMICS MODEL

As the scenarios for the Danube Delta - Black Sea area deal with uncertainties external to the modelled system, they cannot be understood correctly without knowing the exact delineation of this system. What is 'in'? And what is 'out'? What is part of the modelled system? And what is not? This section therefore gives a brief introduction to the system dynamics model developed within COASTAL for this area. Next, an overview is given of the external uncertainties in the system's environment that were taken as a starting point to develop the scenarios.

WHAT DID WE MODEL?

In addition to supporting a high level of biodiversity, the Danube Delta Region provides many benefits for humans (ecosystem services). It has an important impact on water quality and nutrient retention, especially for the Black Sea ecosystems. Moreover, it provides extensive economic and environmental benefits to the entire region: the socio-economic benefits of the wetlands to local communities living in and around the Danube Delta are very important.

The Danube Mouth model combines three of the key economic activities of the region, that are fish farming, agriculture and tourism, and aims to evaluate their development and impact on the water quality under various scenarios. Practically, all aspects of the delta's inhabitants' lives are related to water in one way or another.

For each economic activity, several aspects were considered, namely the supply side (area of farms, crop production, fish production, accommodation capacity), the demand side (fish consumption, number of tourists) and environmental pressures (impact of N from agriculture, fishery, or tourism on water quality). The dynamics of local population income and employed population were also considered.

In addition to this, intensive aquaculture also became of interest because, according to national reports, domestic fish production in Romania represented less than 20% of the internal consumption (2016-2019), leaving production in the 18^{th} place in the EU with 12,798 t (0.93% of total EU production). The rest came from imports. Thus, for 2019, it was estimated that the national consumption was over 120,000 t, representing approximately 195 million euros. This shortfall in domestic production, compared with fish consumption, can be interpreted as a potential for the development of the fisheries sector in Romania (over 100 000 t).

Although from a local economy point of view this development is beneficial, an increase of these economic activities may entail a further deterioration of the environment. And in the long term, due to these environmental pressures, revenues may decrease at the level of each associated sector. Accordingly, one of the combined model's feedback structures for the impact of nitrogen load from aquaculture, agriculture and tourism on the water quality considers the interaction between the mentioned sectors' potential development correlated with fish farming, eco-farming area and the intensification rate of the process, and with the evolution of the tourism carrying capacity and the duration of tourist stays.

(More detailed information about the model structure can be found in COASTAL Deliverable 14.)

WHAT KIND OF EXTERNAL UNCERTAINTIES WERE TAKEN INTO ACCOUNT?

As explained in the introduction of this report, the Shared Socio-economic Pathways (SSPs), complemented with insights from the IPCC report "Global warming of 1.5°C" and the Representative Concentration Pathways (RCPs), were used as a starting point to develop the case-specific scenarios. In the table below (cfr. Table 2), an overview is given of the parameters from this generic framework identified as being system external uncertainties that may affect the behaviour of the model for the Danube Delta Region. The second column displays the input variables where the scenarios connect with the modelled system. The third column lists the parameters from the generic SSPs that were taken into consideration to explain the future evolution of these model-specific input variables.

***Table 2**. Model input variables in relation to system-external uncertainties.*

N°	Model input variable	System-external uncertainties affecting this model input variable
1	Eco crop costs	population growth, urbanisation level, urbanisation type, land use
2	Farm to Fork target	urbanisation level, policy orientation, environment, land use, agriculture
3	Crop farm costs	population growth, urbanisation type, consumption, environmental policy, technology transfer
4	Max fertiliser use	policy orientation, agriculture productivity
5	Danube's flow	Climate change RCP 1.5
6	Annual precipitation	Climate change RCP 1.5
7	Evaporation	Climate change RCP 1.5
8	Fish consumption	population growth, governance
9	Fish price	development of the area, governance
10	Labor costs per employee	development of the area, governance
11	Aquaculture intensification rate	development of the area, technology, land use
12	Duration of tourist staying	economic growth, tourism, development of the area
13	Revenues per tourist day	economic growth, tourism, development of the area

DETAILED DESCRIPTION OF THE SCENARIOS

In total, we developed four scenarios for the Danube Mouths-Black Sea case. Each of them is rooted in the combination of a certain shared socioeconomic pathway (SSP) with a climate scenario linked to RCP 1.5 (which limits global warming to below 1.5 °C, the aspirational goal of the Paris Agreement). The following overview shows the combinations used during the scenario building process:

SCENARIO 1: SSP1 SUSTAINABILITY - TAKING THE GREEN ROAD (Low challenges to mitigation and adaptation) + RCP1.5

In this scenario, regional development respects perceived environmental boundaries (Riahi, 2017). Thus, equity and ethics are important with an emphasis on human well-being and reduced inequality. The Danube Delta's consumers' preferences will diversify, they will consume less meat and more locally produced fish, from non-intensive aquaculture. The ecolabel certification schemes will be developed and implemented, for fish and agri-food products. Due to the high degree of education, there is a higher demand for rural and ecological tourism destinations, including the Danube Delta. The local population in the Danube Delta has responsible behaviour in terms of environmental protection, as well as domestic and foreign tourists. Regarding social responsibility, the concept of a united community exists, and ethics are important and applied. Ecological tourism services are provided to European standards and the offer is close to that of more developed countries. Gastronomic tourism is a favourite option for those who visit the Danube Delta, the tourist prefers to consume fish, dairy, and other traditional, local dishes from sustainable sources. The strategy of decision-makers, local and national administration is focused on environmental conservation and good practices, and massive promotion of eco-tourism. Fewer fossil fuels are being used in the local transport both by tourists and locals and environmental conditions are gradually improving, both for organic agriculture and aquaculture and ecological tourism. Improvements in agricultural productivity are seen through the rapid diffusion of best practices of agroecology. There is a rapid technological change towards environmentally friendly processes, including yield-enhancing technologies. Direct farm payments are replaced by agri-environmental and less favoured area payments. As a result, organic farming cost is decreasing while traditional farming costs are increasing. The capacity to adapt to climate change is high given the well-educated, rich population, the high degree of good governance and the high development of technologies.

This scenario was envisaged by one of the stakeholder groups in our meetings at the start of the project when the main discussion topic for future development of the Danube Delta and Black Sea coastal area was tourism (generating 90% of the GDP). Their vision was that green-friendly tourism should be approached, by promoting electric transportation and clean technologies (e.g. local wastewater treatment) and preserving the specificity of the zone with regards to traditions, folklore, and gastronomy. Households can function as guesthouses, offering accommodation and catering services in an authentic traditional environment. Another development strategy was promoting different types of tourism activities - sophisticated travellers following belletristic itineraries, routes based on ancient ruins (Greek, Roman) or following literary/cultural routes: multicultural cemetery of Sulina, Lighthouse of Sulina, the houses of the old owners, 2 wrecks very well preserved. One of the mayors of the villages on the Danube delta upstream envisaged the village as a mini-port for cruises on the Danube and tourists are following the neighbouring wine and archaeological routes. Agriculture practices in the area should change from large landowners to smaller surfaces cultivated by locals (pre-emption rights) and the resulting products should be used for their livelihood, marketed in local pensions/hotels, and only the surplus (if any) marketed elsewhere.

SCENARIO 2: SSP2 MIDDLE OF THE ROAD (Medium challenges to mitigation and adaptation) + RCP1.5

In this scenario, urbanization reaches an average level in the hinterland, though the type depends on the specificities of the area. Furthermore, expertise, practices and field productivity of organic agriculture reach an average level; and other technological trends do not shift markedly from historical patterns (Riahi, 2017). In the Danube Delta, farmers and fish farmers are beginning to specialize and the quality of the labour force improves. The performance of the agricultural, including aquaculture, and tourism sectors is improved by means of investments in sanitary, water and health infrastructures. Although meat consumption is maintained at an average level in the area, the culinary preferences of the inhabitants and tourists are diversified, and the structure of the offer of agri-food products is at the level of the links present in the value chain. Marketing policies begin to facilitate local producers' access to the market of agri-food products, depending on their production specifics. Environmental policies are focused on reducing pollution, but the impact of these actions is medium in the long term and the Danube Delta's ecosystems still experience degradation. In addition to this, energy from renewable sources is accepted and implemented more and more at the level of individual entrepreneurs in tourism and agriculture. Yet, environmental challenges stay high on the agenda, especially biodiversity decline, ecosystem degradation and the shrinking area for organic farming.

In our opinion, this scenario is in line with the 2030 vision for the Danube Delta "An attractive area – with precious biodiversity and vibrant, small/medium scale (artisanal and modern) agriculture and business - where people live in harmony with nature; integrating economies of tourism, farming, and fishery; and supported by urban service centres". This scenario was envisaged by other stakeholder groups in the form of marine aquaculture's development in the sense that they foresee a future legal settlement of the water body concession issue and the implementation of the shellfish areas' sanitary-veterinary classification for safe human consumption. For fish farming, on land recirculating aquaculture systems (RAS) are the solution. In a long-term timeframe, four shellfish farms, one cage fish farm in the open sea and two RAS fish farms on land are desired. Another potential development direction could be the capitalization of chlorophyll from micro and macroalgae.

With regards to tourism development, the developmental trend is clear and leads from classic tourism to eco-tourism. The Danube Delta, a rather expensive destination, will be visited especially by foreign tourists who seek beautiful landscapes and nature, birdwatching and local traditions. For inland rural areas the future relies on integrated agriculture, namely each community should focus on a complete integrated production cycle: from cereals, animal farming and processing units to final consumption products. Moreover, lower interest rates for credits and more subsidies are desirable, together with incentive schems to adapt novel technologies (e.g. smart irrigation systems).

SCENARIO 3: SSP4 INEQUALITY - A ROAD DIVIDED (Low challenges to mitigation, high challenges to adaptation) + RCP1.5

In this scenario highly unequal investments in human capital, combined with increasing disparities in economic opportunities and political power, lead to increasing inequalities and stratification across the country (Riahi, 2017). As a consequence, tourism becomes a practical activity only for the people with a high-income level. As a result of this, the number of those who earn their living in the field of tourism is decreasing, as well as their incomes. The impact of tourism on the water quality, on the other hand, is lower. But policymakers' interest in improving environmental policies decreases and tends to focus on local issues in places where, on average, more middle- and high-income households live. The institution defends the interests of those economic agents with higher incomes and underestimates the importance of economic agents with lower turnovers.

The agricultural productivity is high in this scenario for large-scale industrial farming, and low for small-scale farming. Fish is obtained from the cheapest sources, even from the supermarket. The lack of environmental concerns leads to disasters. The labour force is cheap even though technological development and automation are considered important.

SCENARIO 4: SSP5 FOSSIL-FUELED DEVELOPMENT - TAKING THE HIGHWAY (High challenges to mitigation, low challenges to adaptation) + RCP1.5

In this scenario strong investments are made in health, education and other institutions to enhance human and social capital (Riahi, 2017). The agricultural sector is modelled in line with global standards, the chains of agri-food products' capitalization are integrated horizontally and vertically, aquaculture is intensified and the fish products industry is growing massively. Local consumerism and consumers' preferences align with rich meat and fish diets and industrial products obtained from meat processing. More vegetarian diets rich of fruits and local vegetables are less developed.

Industrialization trends in conventional agriculture are enforced and the labour force in agriculture, aquaculture and the touristic sector is grown. There tends to be a massive use and exploitation of fossil fuels in all the economic activities of interest in the case study area. Besides that, also massive deforestation in the forests of the Danube Delta, but also in Tulcea County in general, can be noticed. Policymakers establish governance frameworks making a big difference between man-made systems and natural systems.

REPRESENTATIVE CONCENTRATION PATHWAY (RCP1.5) - DANUBE RIVER

There is a high agreement that air temperature is likely to increase in the future with a gradient from northwest to southeast, both annually and seasonally. For the future period (2021 – 2050) an increase in annual mean temperature between 0.5°C in the upper basin parts and up to 4°C in the lower basin parts of the Danube River Basin (DRB) are projected (ICPDR, 2018). Romania is situated in the lower basin, so, the 1.5°C is considered appropriate. Since the DRB is in a transition zone between increasing (Northern Europe) and decreasing (Southern Europe) future precipitation, overall small precipitation changes are to be expected. The mean annual precipitation sum is likely to remain almost constant with an intensification in seasonal changes. A strong decrease in summer precipitation and an increase in winter precipitation will be most likely. Particularly in the south-eastern parts a reduction of about 25 % and 45 % is shown in the scenario results (ICPDR, 2018). Accordingly, for RCP1.5 we considered a reduced Danube's flow by 10 %.

In the remaining part of this section, future evolutions under each of the four scenarios developed for the Danube Delta region are described qualitatively making use of each of the variables listed in the second column of Table 2 above. Via the following repository link all quantitative data corresponding with these qualitative descriptions can be accessed easily: https://doi.org/10.5281/zenodo.6832792

1. VARIABLE: ECO CROP COST

Scenario 1
In the green scenario, the level of subsidies for organic farming will increase, so this led to a reduction of the eco crop cost. We estimated a decrease of 10% compared to a business as usual scenario, resulting in a value reaching 2835 lei/ha/year compared to 3150 lei/ha/year, which is the present value.

Scenario 2
This scenario corresponds to the present, with a set value of 3150 lei/ha/year for the eco crop cost value, resulting from current practices.

Scenario 3
Due to the decrease in demand for local organic products, the production costs will increase by 10% and prices will follow a downward trend. The new value set for this variable will be 3.465 lei/ha/year.

Scenario 4
The production specialization of large farms results in a narrow range of domestic food products. However, a small group of producers produce organic products or luxury items with on-farm processing. The new value set for this variable in this scenario will be 3811.5 lei/ha/year (+20%).

2. VARIABLE: FARM TO FORK TARGET

Scenario 1
The environmental standards are expected to be high under SSP1 (Riahi, 2017; Mitter, 2019), so the share of organic farming is expected to be higher than planned (25%). Therefore, we considered a higher value of the variable (30%).

Scenario 2
The environmental standards are expected to be medium under SSP 2 (Riahi, 2017; Mitter 2019), so the share of organic farming is expected to increase slowly. Therefore, we considered this scenario as BAU, keeping the value of the variable to the expected situation of 25%.

Scenario 3
Environmental standards are expected to be low under SSP4 (Riahi, 2017; Mitter 2019), so the share of organic farming is expected to increase slower than targeted. Therefore, we considered the value to increase up to 15%.

Scenario 4
Environmental standards are expected to be lowest under SSP5 (Riahi, 2017; Mitter 2019), so organic farming practices are expected to decrease. Therefore, we decided to decrease the value up to 8%.

3. VARIABLE: CROP FARM COSTS

Scenario 1
In the green scenario, the level of subsidies for conventional farming will decrease, so this led to an

enlargement in the crop cost, we estimated +10% compared to today, this value reaching 4620lei / ha/year compared to 4200 lei/ha/year.

Scenario 2

This scenario corresponds to actual conditions, with a set value of 4200 lei/ha/year for the crop cost value.

Scenario 3

Due to the increase in demand for local agri-food products, the production costs will decrease by 10% and prices will follow a growing trend. The new value set for this variable will be 3780 lei/ha/year.

Scenario 4

The new value set for this variable in this scenario (-20%) will be 3402lei/ha/year.

4. VARIABLE: MAX FERTILISER USE

This value is set in the model as this variable is observing the Good agricultural practices recommendations. This maximum can only be modified if the yields will increase. Therefore, Scenario 2 represents 2020 data. For all other scenarios, in alignment with RCP 1.5, it is expected that yields decrease by 5%. Additionally, an increase of 10% was set for scenario 3 and 20 % for scenario 4.

5. VARIABLE: DANUBE'S FLOW

Under RCP1.5, the mean annual precipitation sum is likely to remain almost constant, though with an intensification of seasonal changes. A strong decrease in summer precipitation and an increase in winter precipitation will be most likely. Particularly in the south-eastern parts a reduction of about 25 % and 45 % is shown in the scenario results (ICPDR, 2018). For RCP1.5 we considered a reduction of the Danube's flow of 10 %.

6. VARIABLE: ANNUAL PRECIPITATION

Climate impacts vary dramatically across Europe, with southern Europe becoming hotter and drier, while northern Europe becoming warmer and wetter. If we meet the 1.5°C targets, impacts will be limited – for example, annual average precipitation would decrease by less than 10% in the worst affected regions (Harrison, et al., 2019).

7. VARIABLE: EVAPORATION

The value for this variable is 750 mm/year in the case study area (Paltineanu, 2008). Under RCP 1.5 conditions, this value increases by 3% (Donnelly et al., 2017), so for all the four scenarios the set constant value will be 773 mm/year.

8. VARIABLE: FISH CONSUMPTION

Within the European Union, the average consumption of fish is 23.3 kg/person/year. Consumption varies from 4.6 kg/person/year in Bulgaria to 61.6 kg/person/year in Portugal. World population size is a key driver of seafood demand, as is the relative affluence of citizens (Garcia & Rosenberg 2010). In 2007, Failler et al., published fish consumption, production (capture, aquaculture, and commodities) and fish trade (exports and imports) estimates and projections for 28 countries from 1989 to 2030. The projections suggest an increase in the demand for seafood products by 2030, driven by both increases in the human population size of European countries, but also changes in per capita fish consumption (CERES, 2017). The variable is used to calculate the fish consumption connected to the number of annual days spent by tourists in the Danube Delta modelled in the tourism sub-model, local population (14300) and population of the southeast region of Romania (2 mil.).

Scenario 1

The variable gradually increases until 2030 and reaches then plus 10% only from normal aquaculture.

Scenario 2

The variable has a regular increase until 2030. Then the fish consumption reaches an increase of about 100% both from normal and intensive aquaculture.

Scenario 3

The variable has a regular increase until 2030. Then the fish consumption reaches the European average, which represents an increase of about 300% both from normal and intensive aquaculture.

Scenario 4

The variable has a regular increase until 2030. Then the fish consumption overpasses the European average, which means an increase of about 400% from intensive aquaculture.

9. VARIABLE: FISH PRICE

Scenario 1

Moderate economic growth is anticipated, although slightly more rapid in eastern European countries. Fishmeal prices are moderately high, due to the limited availability of sustainable sources. The fish price is moderately increased, but lower than in scenario 2 (+20%).

Scenario 2

Moderate economic growth is anticipated, although slightly more rapid in eastern European countries. The fish price is moderately increased (+25%).

Scenario 3

Rapid economic growth is anticipated in many Eastern European countries (most notably Bulgaria, Romania, Turkey, Latvia, Macedonia, and Albania), contrary to Western European countries where a more modest growth is expected. The fish price is low, increasing by only 5%.

Scenario 4

Rapid economic growth is anticipated in many Eastern European countries (most notably Bulgaria, Romania, Turkey, Latvia, Macedonia, and Albania), contrary to Western European countries where a more modest growth is expected. The fish price is low, increasing by only 5%.

10. VARIABLE: LABOR COSTS PER EMPLOYEE

The average growth rate over the coming 8 decades, based on the OECD's GDP projections, varies from a low 1.6%/year to nearly the double (3.1%/year). Like the population trends, there is some clustering at the global level, with SSP3 and SSP4 quite close together and SSP1 and SSP2 with rather a similar shape.[1]

Scenario 1
The labour costs are moderate, increasing by +2.4%.

Scenario 2
The labour costs are the same as in scenario 1, and hence increase by +2.4%.

Scenario 3
The labour costs are moderate, increasing by +3.1%.

Scenario 4
The labour costs are high and increase with 10%.

11. AQUACULTURE INTENSIFICATION RATE

The aquaculture intensification rate is the lowest in Scenario 1 because the consumption of fish from fishing and normal aquaculture are preferred. With the increase of urbanization (Scenario 2) the need to intensify aquaculture also increases, provided that it respects ecological norms and production capacities. In the last two scenarios the intensification of aquaculture is increasing, yet its production has different purposes and serves different goals, namely economic growth that benefits the elite (Scenario3), and cheap junk food of poor quality that is extremely processed (Scenario 4).

Scenario 1
The aquaculture intensification rate is at its lowest level: 0.01.

Scenario 2
The aquaculture intensification rate is moderate: 0.05.

Scenario 3
The aquaculture intensification rate is high: 0.08.

Scenario 4
The aquaculture intensification rate is at its highest: 0.1.

[1] https://gtap.agecon.purdue.edu/resources/download/7554.pdf

12. VARIABLE: DURATION OF TOURIST STAYING

Scenario 1

Because the Danube Delta has the potential to develop high-quality ecological tourism, people will stay longer in this area in a green scenario. So, in this case, the duration of tourists staying will therefore increase with 36%. We approximated this increase following one of the meetings held with the stakeholders in the field, regarding the dynamics of this variable, in the context of a green scenario. The expertise of the involved stakeholders places the duration of tourist stays at 4 accommodation days instead of 3, the value considered initially.

Scenario 2

Due to the moderate environmental degradation specific to scenario 2, the duration of the tourists' stays in the Danube Delta area will be constant at the beginning of the interval (remaining at 2.2 nights/tourist stay), and will then decrease slightly, with 30% reaching the value recorded at the beginning of the interval in scenario 1.

Scenario 3

Because in this scenario only the people with financial possibilities are the ones who will go on vacation, while also considering that the Danube Delta area does not necessarily target rich people, the duration of tourists will decrease by 30%.

Scenario 4

Scenario 4 is characterized by mass industrialization of economic activities, a strategy that does not encourage the development of ecotourism in the Danube Delta. So those who will come to the case study area will be less. We considered a decrease of 22%.

13. VARIABLE: REVENUES PER TOURIST DAY

Scenario 1

Due to the growth of the ecological tourism market in the Danube Delta, the tourist offer will be accessible at a higher price. We calculated an increase of 17%.

Scenario 2

Revenues received after a tourist day will be constant at the beginning of the interval, and will then decrease slightly, depending on the declining tourist demand due to environmental degradation specific to the conditions under SSP2. We estimated a decrease in the value of this variable by 13%.

Scenario 3

Because in this scenario the consumers of touristic services are people with high financial possibilities, the price of a tourist day on vacation will increase compared to the one practised today. We considered an increase of 60%.

Scenario 4

Due to an increase in the living standards of the population in the Danube Delta, the cost of a tourist day in the area will increase slightly with 10%.

COMPARISON OF THE DYNAMIC PATTERNS OF KEY MODEL VARIABLES

We investigated how changes in the modelled system's environment, according to different scenarios, impact the functioning of this system, and hence the patterns of key variables. We ran the model under each of the four described scenarios and changes in exogenous variables – fish consumption, fish price, labour costs, duration of tourists' stay, crop cost, farm to fork target, etc.

The Danube's Mouths – Black Sea model has different key performance indicators (KPI) concerning several social, economic, and environmental aspects (see also Table 3).

Table 3. *Scenario variables' values under different scenarios and key performance indicators (KPI).*

Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4	KPI
Aquaculture					
Fish consumption factor	+10%	+300%	+100%	+400%	1. Intensive fish farming area 2. Total aquaculture production 3. Fish consumption 4. Impact of nitrogen load from aquaculture
Fish price	+20%	+25%	+5%	+5%	
Labour costs	+2.4%	+2.4%	+3.1%	+10%	
Aquaculture intensification rate	0.01	0.04	0.08	1	
Tourism					
Duration of tourist stay	+36%	+30%	-30%	-22%	5. Annual tourist days 6. Tourism revenues 7. Tourism pressure 8. Impact of nitrogen load from tourism
Revenues per tourist	+17%	-13%	+60%	+10%	
Agriculture					
Eco crop cost	-10%	0%	+10%	+20%	9. Eco farm production 10. Traditional farm production 11. Total agricultural income 12. Fraction ecofarms 13. Impact of nitrogen load from agriculture
Crop farm cost	+10%	0%	-10%	-20%	
Farm to fork	+30%	0%	+15%	-8%	
Max. fertiliser use	-5%	0%	+10%	+20%	
Climate change					
Danube's flow	-10%	-10%	-10%	-10%	
Evaporation	+3%	+3%	+3%	+3%	
Precipitation	-10%	-10%	-10%	-10%	

KPI 1: INTENSIVE FISH FARMING AREA

The moderate intensive fish farming (4 t/ha) area depends on the aquaculture intensification rate and development in the different SSPs. Scenarios 1 and 2 show the same pattern with a steady increase that reaches 11 % and 66 % of the total surface in 2050 (NAFA, 2021). Scenarios 3 and 4 have almost the same endpoint, representing 87% and 97% with a different rate of increase, which is very sharp for scenario 4 when the maximum is reached in the first 5 years (Figure 1).

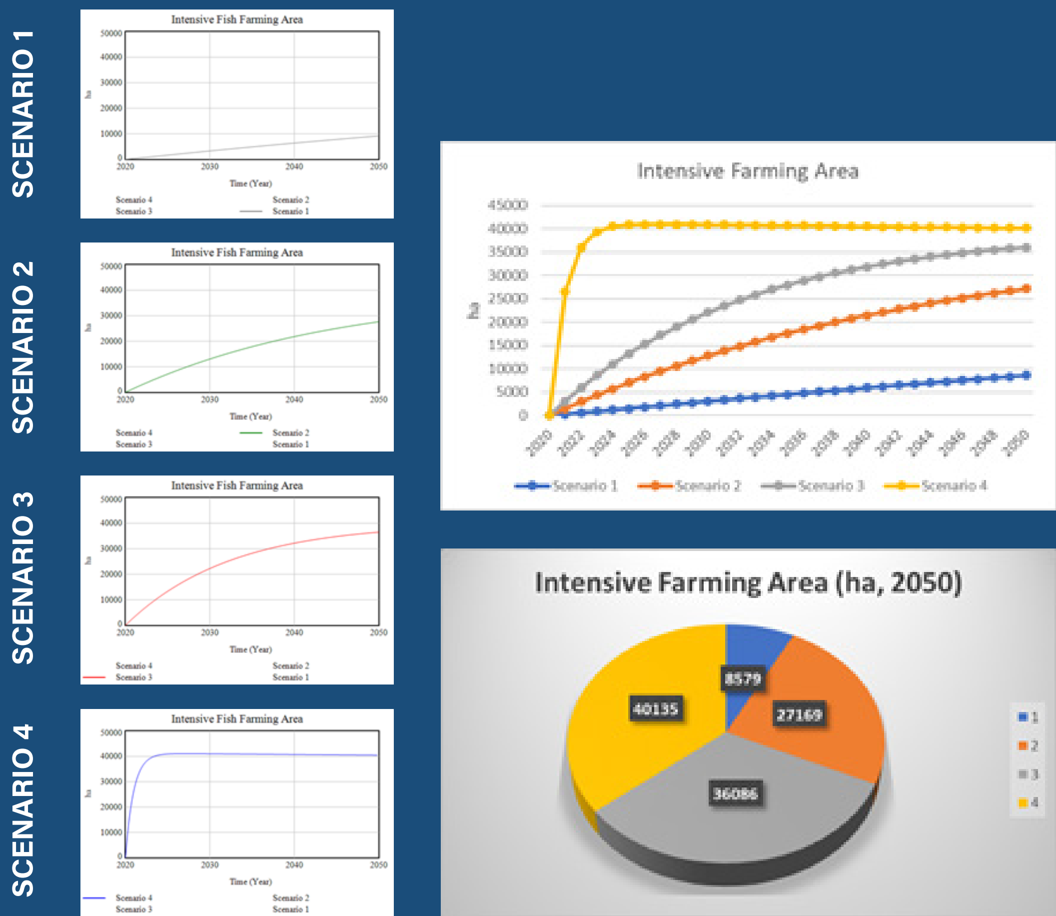

Figure 1: Intensive fish farming area under different scenarios.

KPI 2: TOTAL AQUACULTURE PRODUCTION

The total aquaculture production represents the sum of normal aquaculture and intensive aquaculture production which directly depends on the area used for normal or intensive aquaculture. Like KPI 1, scenarios 3 and 4 show the highest production. Scenario 4 shows the highest increase rate in the first 5 years and reaches the target that can be interpreted as a potential for the development of the sector in Romania (over 100 000 t) (Figure 2). However, this analysis was done only for freshwater aquaculture, so we should also consider the future marine aquaculture potential in the area - as was discussed with the FLAG representative.

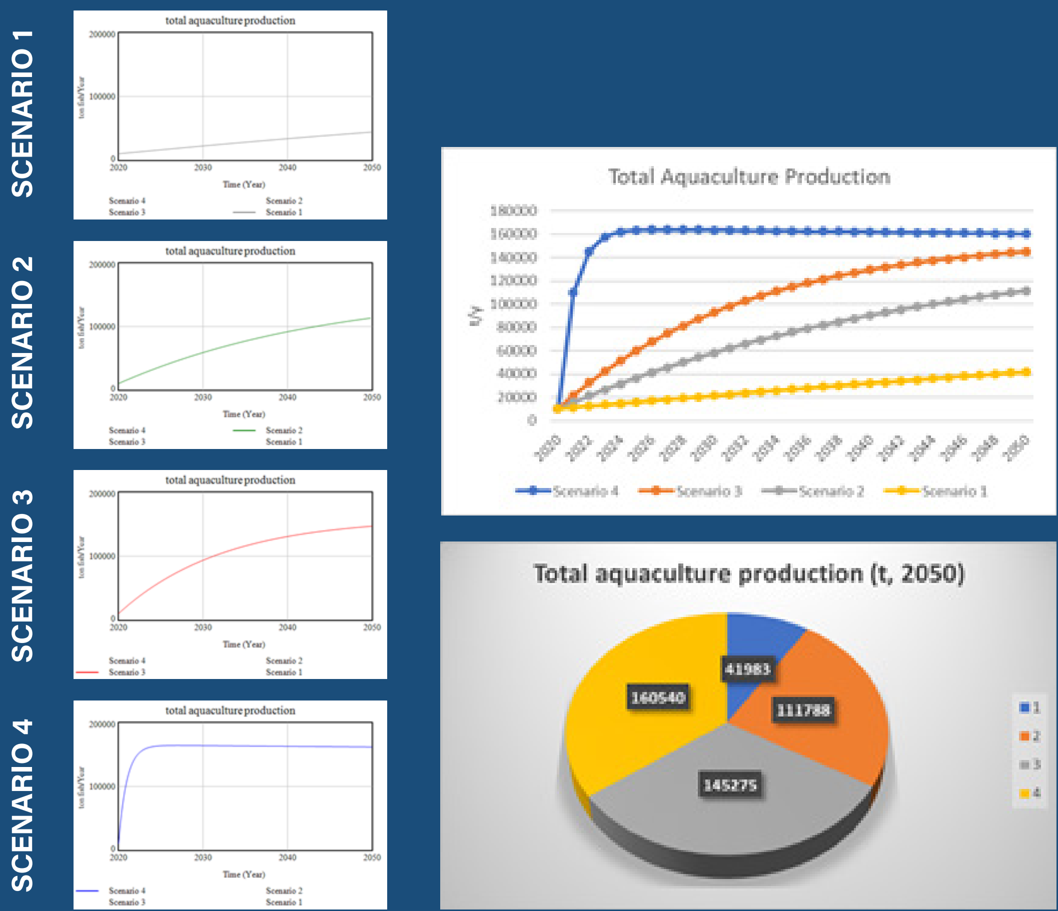

***Figure 2**: Total aquaculture production under different scenarios.*

KPI 3: FISH CONSUMPTION

In Romania, sustainable fish consumption requires encouraging relevant organizations to present aquaculture to customers as one of the solutions for protecting the environment (Rosca, 2014). Thus, producers, vendors and distributors can cooperate to present themselves in front of the customers with honest retailing practices, either for captures or aquaculture. Without, the organizations assuming the role of sustaining a fish consumption based on solutions with low environmental risks, the behaviour of consumers would hardly let itself change (Rosca, 2014). The highest fish consumption, overpassing the European average, is obtained in scenario 4, while the lowest is resulting from scenario 1 (see also Figure 3).

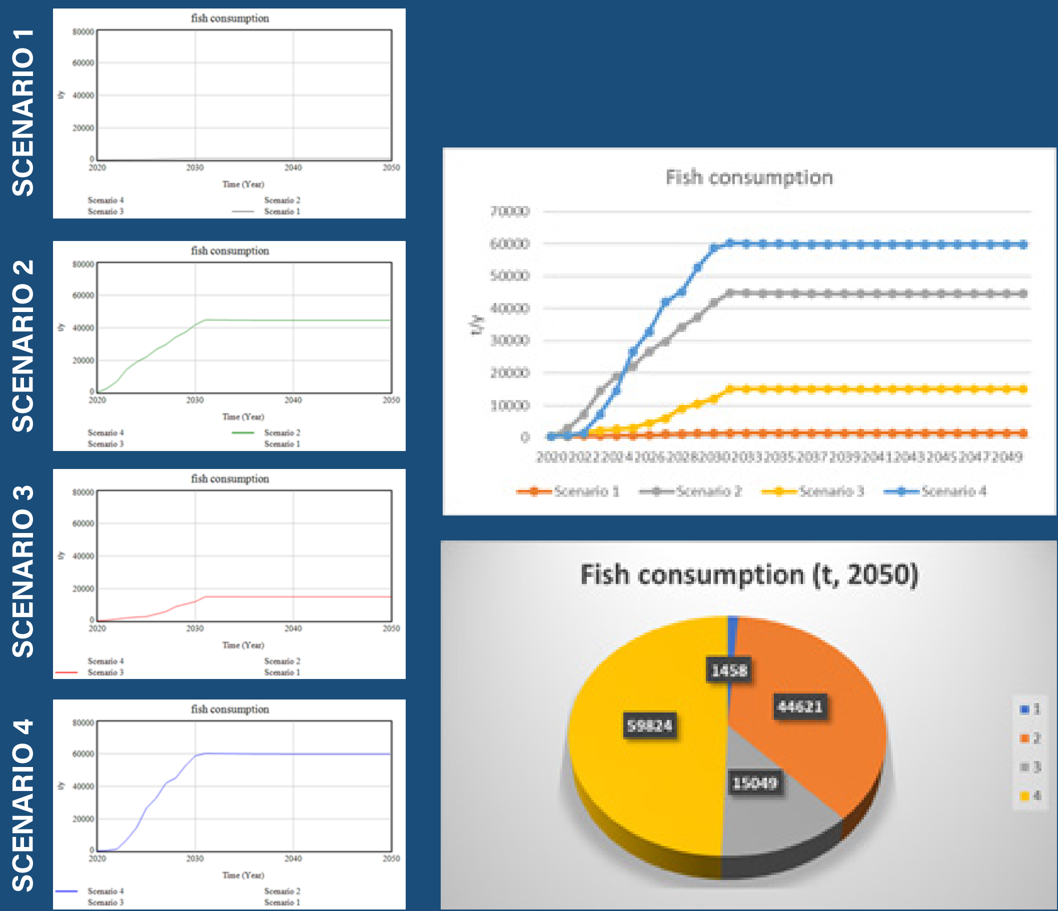

__Figure 3__: Fish consumption under different scenarios.

KPI 4: IMPACT FROM NITROGEN LOAD FROM AQUACULTURE ON WATER QUALITY

One of the submodel key performance indicators (KPI) according to the COASTAL project's main objective is the impact of nitrogen load from aquaculture on the water quality. The indicator is calculated as "grey water" (Hoekstra et al.,2011) and depends on the total aquaculture N load divided by the Danube's flow and maximum nitrogen acceptable concentration according to the current national legislation (Ord.161/2006). The strongest impact of nitrogen load from aquaculture resulted in scenario 4 while the lowest was from the "Green Road" scenario (Figure 4).

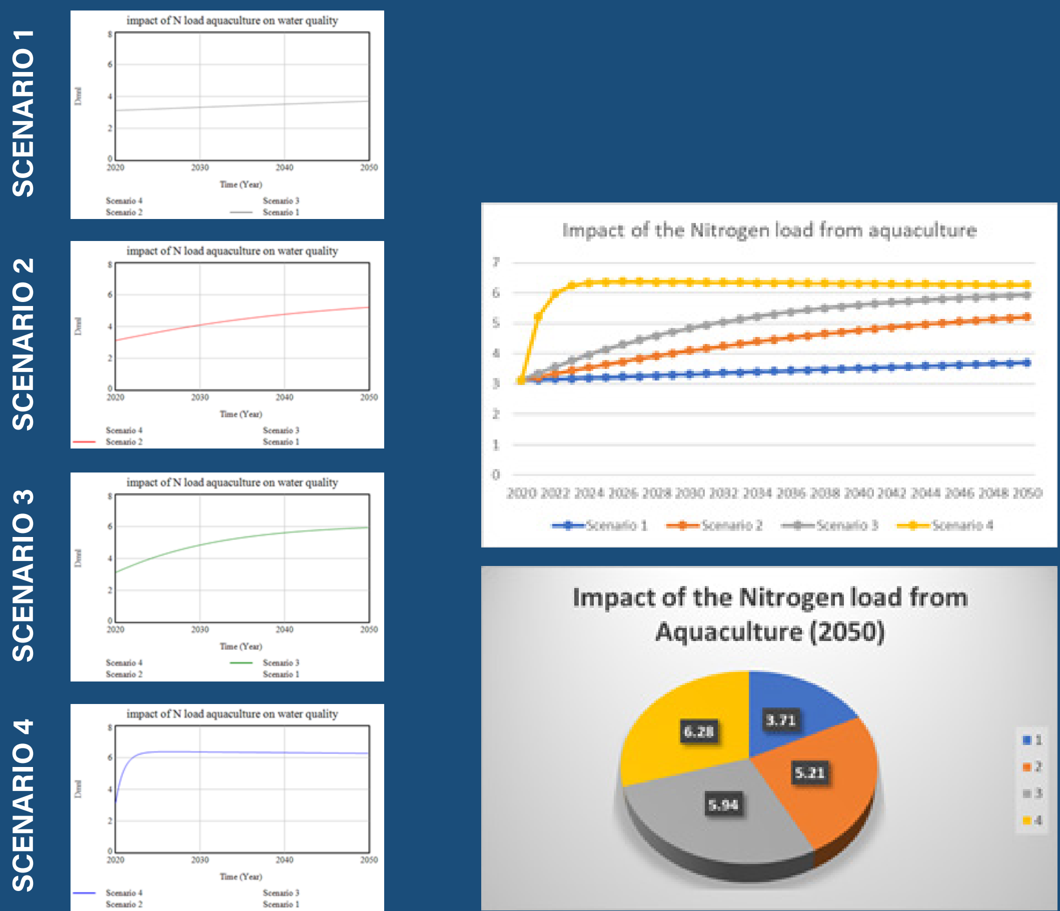

***Figure 4**: Impact of nitrogen load from aquaculture on water quality under different scenarios.*

KPI 5: ANNUAL TOURIST DAYS

“Annual tourist days” is defined by the ratio between the number of annual tourists who choose the Danube Delta as a holiday destination and the average length of their stay. In scenario 2 the average duration of a tourist stay has a value of 2.2 days/tourist. This value was defined by both statistical sources and stakeholder opinions. As shown below, it is observed that in scenario 1 the maximum value is reached and in scenario 3 the minimum value (sea also Figure 5). The model also includes a critical threshold reflecting the number of tourists who can stay in the Danube Delta area without endangering the environment.

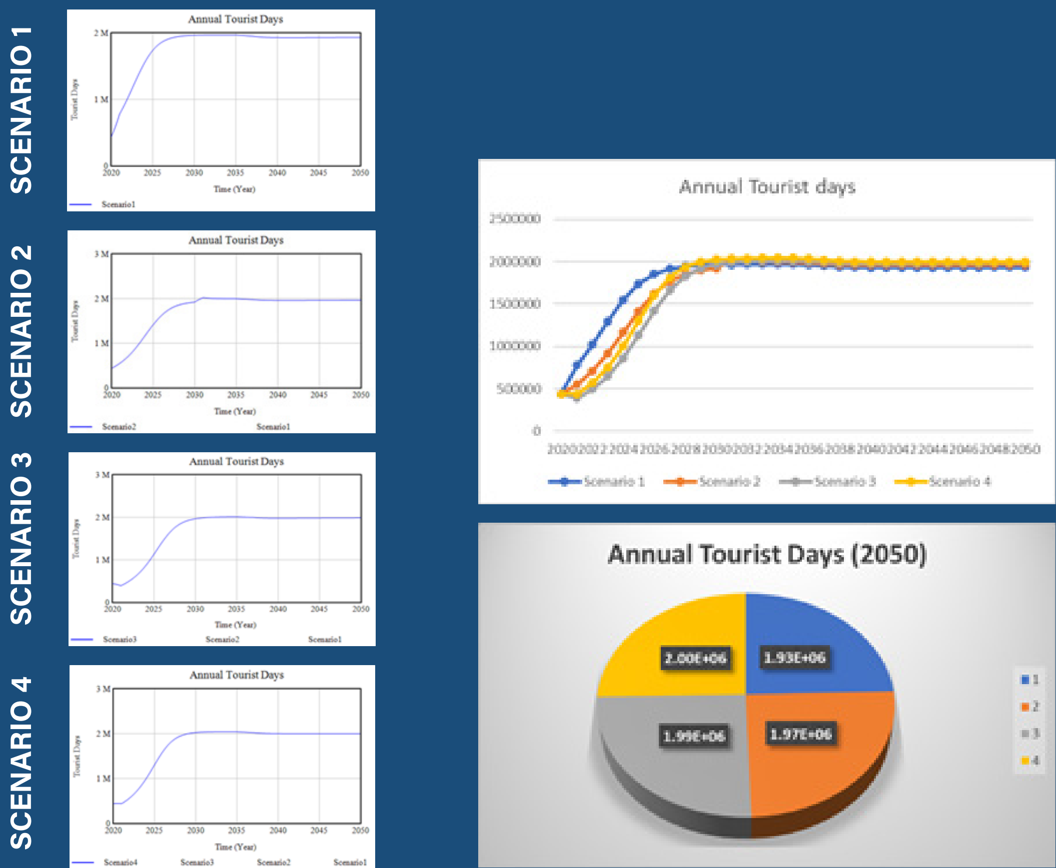

***Figure 5**: Annual number of tourist days under different scenarios.*

KPI 6: TOURISM REVENUES

"Tourism revenues" is a KPI linked to the previous one, namely "Annual tourist days". The higher the number of tourists in the Danube Delta is, the higher the revenues in this sector will be. On the other hand, it must be taken into account that the prices of the tourist offers are volatile, because they are depending on the demand. A high tourist demand influences an increase in the prices of tourist services (Figure 6). In 2021, according to the National Institute of Statistics, a tourist accommodation day in the Danube Delta costed approximately 81 RON, which is about 17 euros (based on the revenues indicator and the number of tourist days calculation).

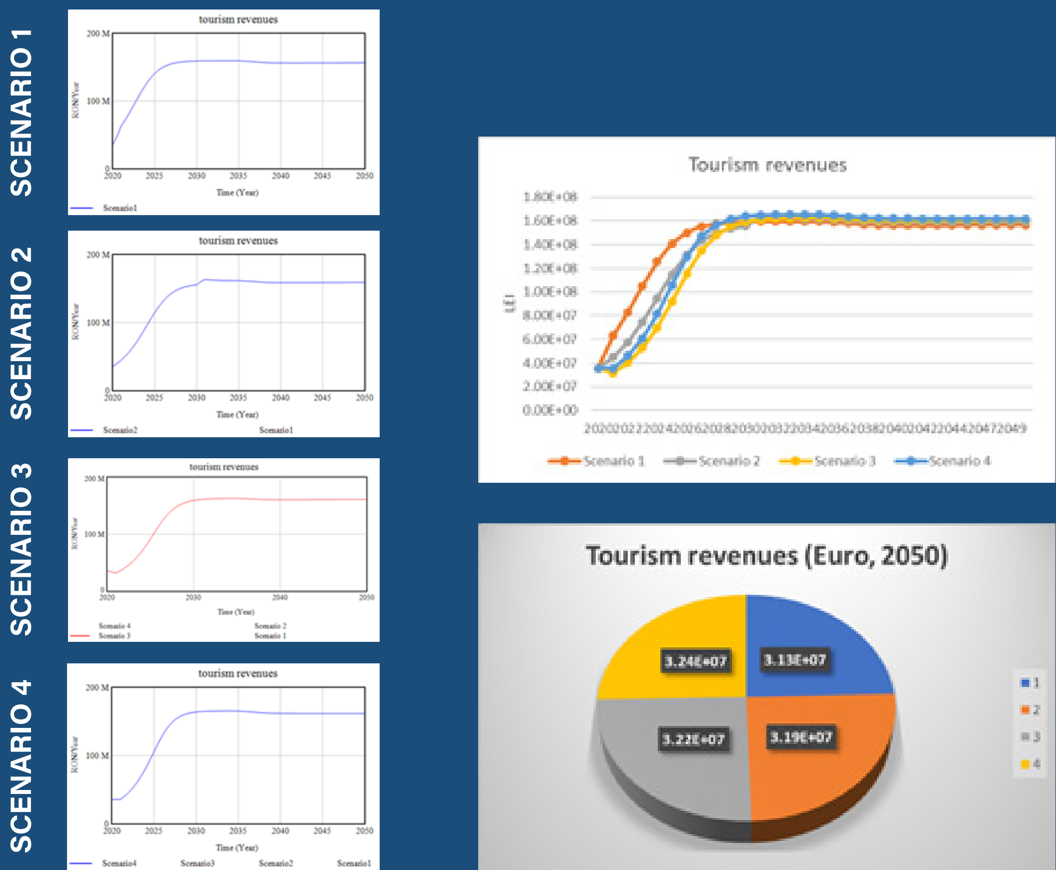

Figure 6: Tourism revenues under different scenarios.

KPI 7: TOURISM PRESSURE

"Tourism pressure" is represented by the ratio between the annual tourist days and the carrying capacity. In scenario 4 the pressure from tourism reaches the highest level, and in the "Green Road" scenario, we observe the lowest pressure on the Danube Delta's natural environment (Figure 7). However, we note that in all 4 scenarios, tourism harms the environment, in a smaller or larger proportion.

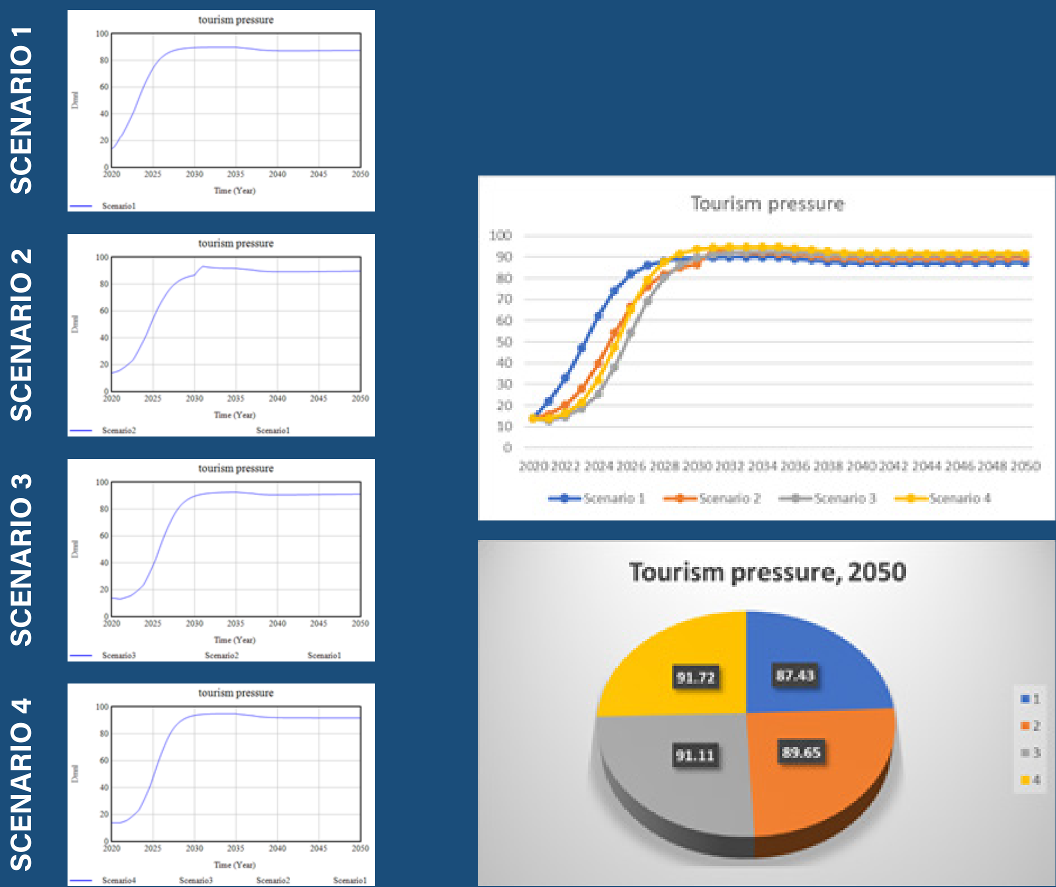

***Figure 7**: Pressure from tourism under different scenarios.*

KPI 8: IMPACT OF NITROGEN FROM TOURISM ON WATER QUALITY

The footprint of tourism is reflected in the evolution of "Impact of nitrogen from tourism on water quality" under different scenarios. As we can observe in Figure 8, touristic activities have an important impact on water quality. The "impact of nitrogen from tourism on water quality" is calculated by dividing the total tourism N load on the Danube flow and the maximum nitrogen acceptable concentration value, which is regulated by legislation that is in force already today. This KPI reaches the highest value in Scenario 4 and Scenario 3, and the smallest value in Scenario 2 (Figure 8).

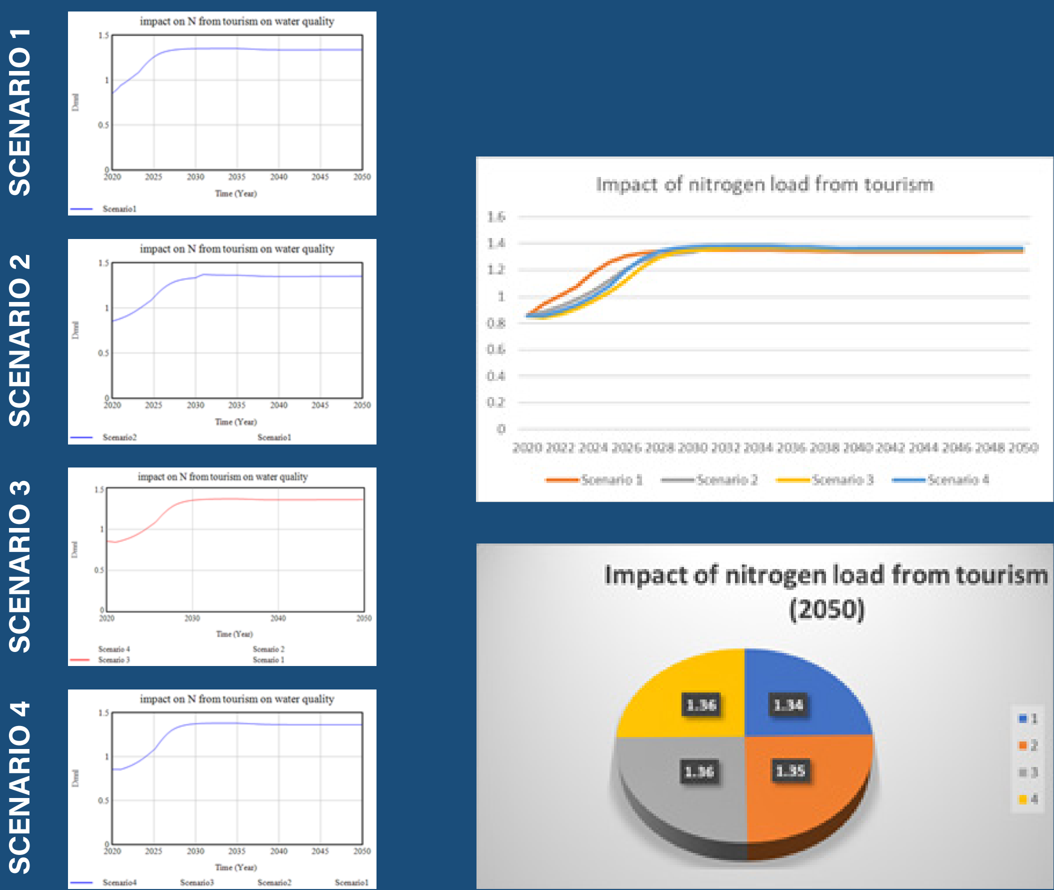

Figure 8: Impact of nitrogen from tourism on water quality under different scenarios.

KPI 9: ECO FARM PRODUCTION

Eco farm production is defined by multiplying the registered yield and the ecological agricultural surface in the case study area. Before conventional agriculture production can become ecological, traditional farms must follow a conversion period of at least two years (MADR). In scenario 2, and also in the “Green Road” scenario, eco-farm production reaches the highest level. This value is characterized by a growing trend. In scenario 4, on the other hand, the lowest ecological production is recorded. We can observe in Figure 9 the symmetry between the increase and the decrease of the eco-farming production through all scenarios.

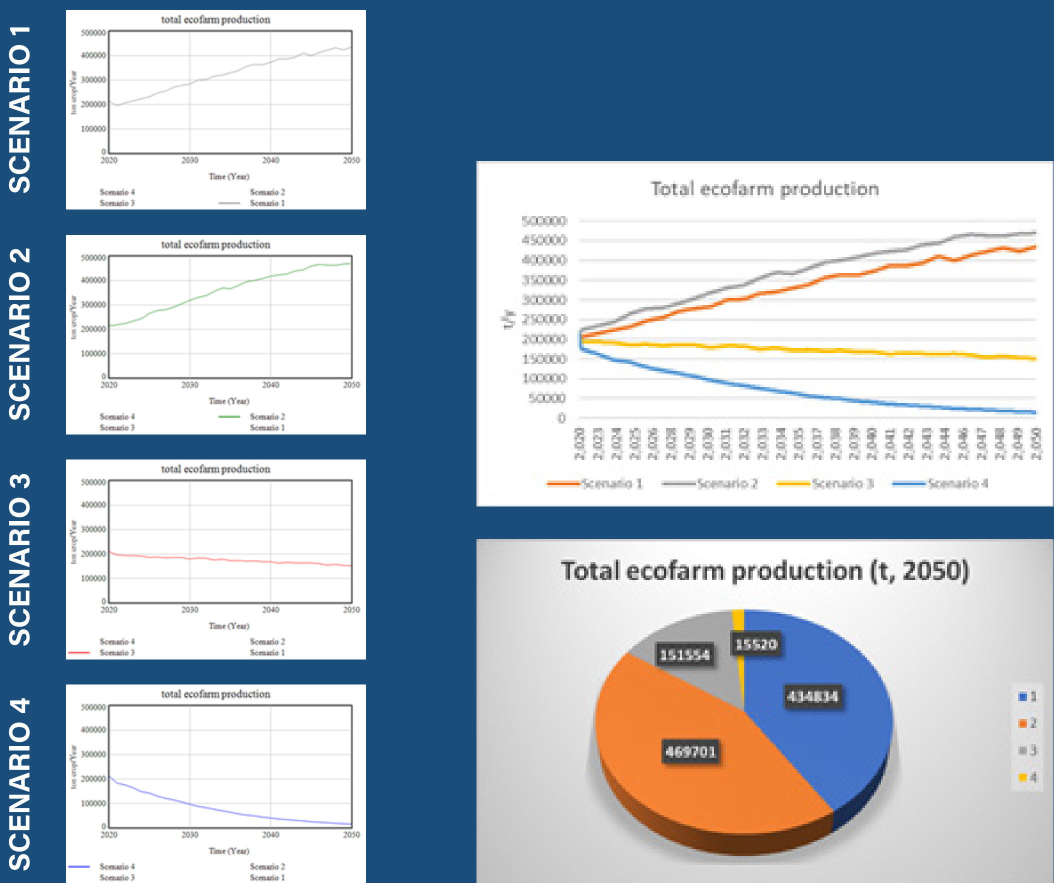

***Figure 9**: Ecofarm production under different scenarios.*

KPI 10: TRADITIONAL FARM PRODUCTION

The evolution of the production of the traditional farms under the 4 scenarios is presented in Figure 10. The dynamic of this KPI is influenced by the productivity registered at the level of the traditional farms and by the area used for conventional farming. It can be observed that in Scenario 1 and Scenario 2, where the ecofarm conversion rate is at a higher level, the total traditional farms' production decreases, while in the last scenarios there is an increase of the traditional farms' production, which reaches the highest level in Scenario 4.

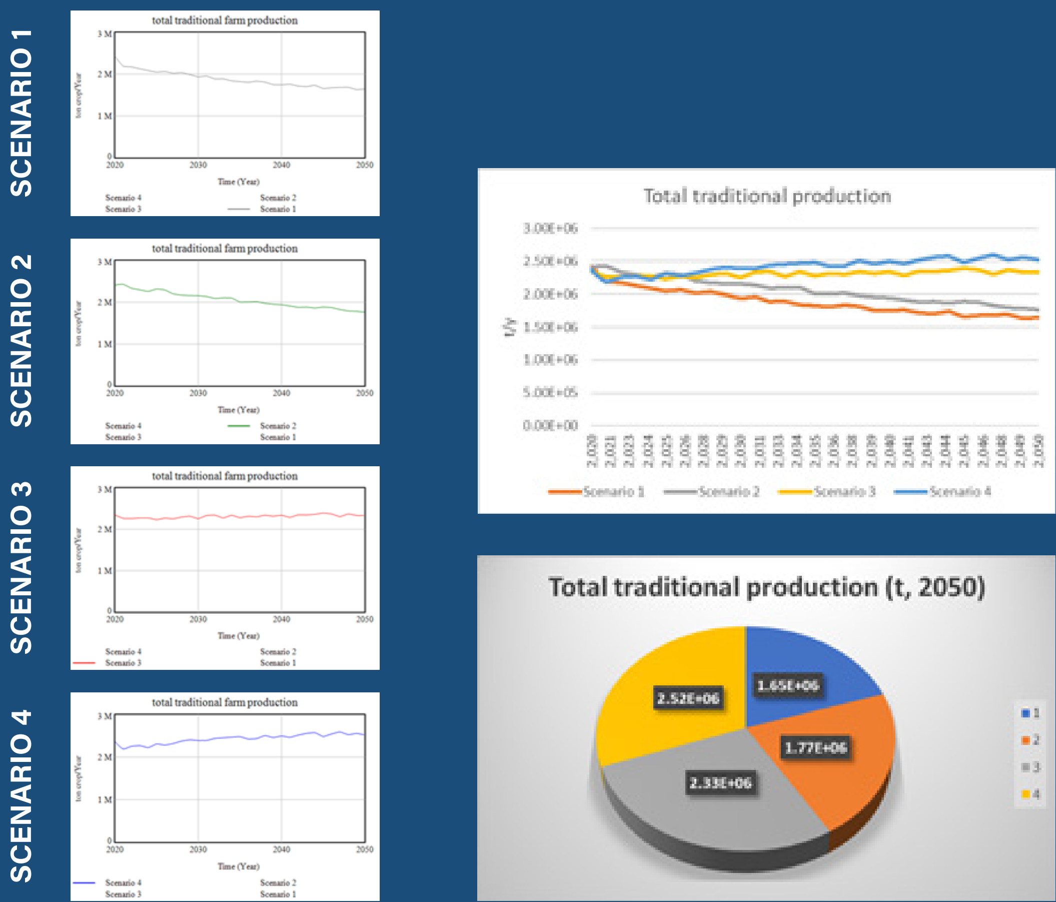

***Figure 10**: Traditional farm production under different scenarios.*

KPI 11: TOTAL AGRICULTURAL INCOME

The agricultural income is defined by summing the revenues of the farmers that practice eco-farming and the income obtained by the traditional farmers, while considering factors such as traditional and ecological crop price, production costs and surface. In figure 11 we can observe that the total agricultural income achieves the highest point in scenarios 2 and 1. Based on figure 11 and figure 10, it can be stated that the highest eco-farm production in the Danube Delta leads to the highest level of income in the agriculture field.

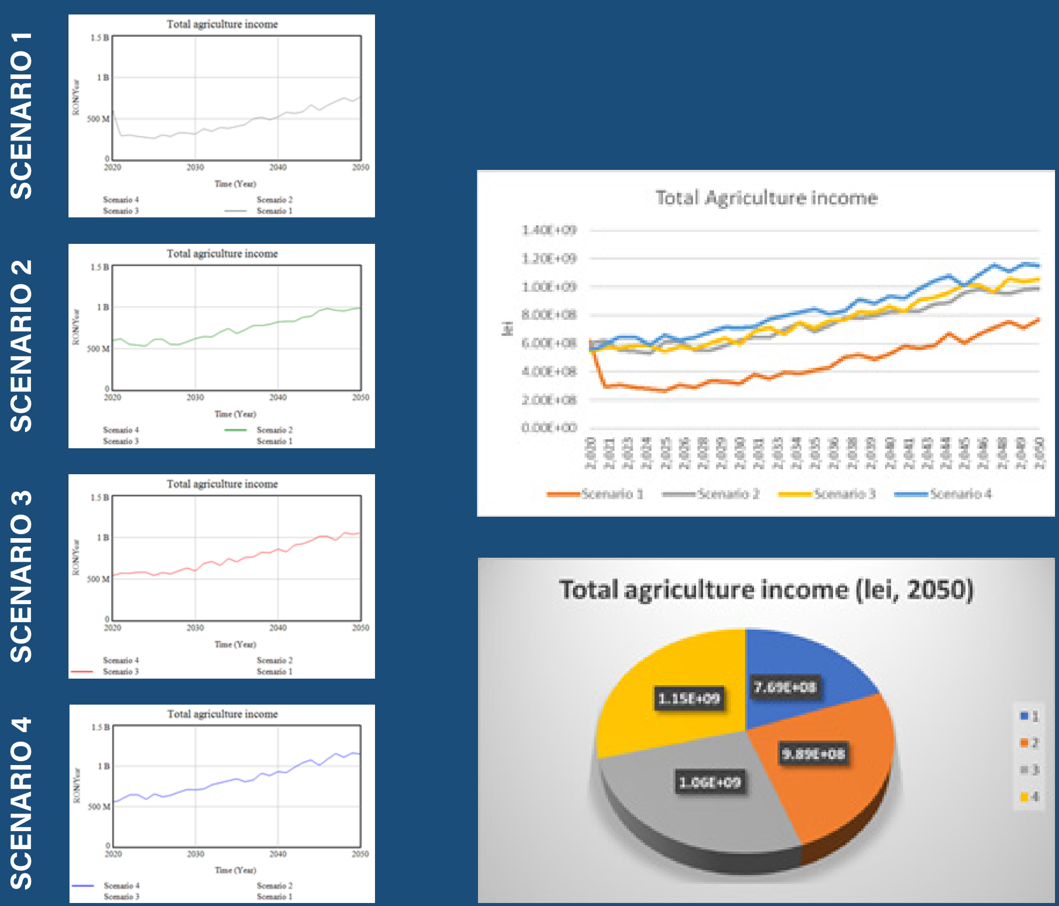

Figure 11: Total agricultural income under different scenarios.

KPI 12: FRACTION ECOFARMS

The “fraction eco farms” is defined by the eco farm area divided to the total, both traditional and ecological. We can observe that this KPI reaches the highest values under Scenario 1 and Scenario 2, and the lowest values in the last two discussed scenarios (Figure 12). This dynamic is influenced by the ecofarm transition rate, considering the “Farm to fork” target as well.

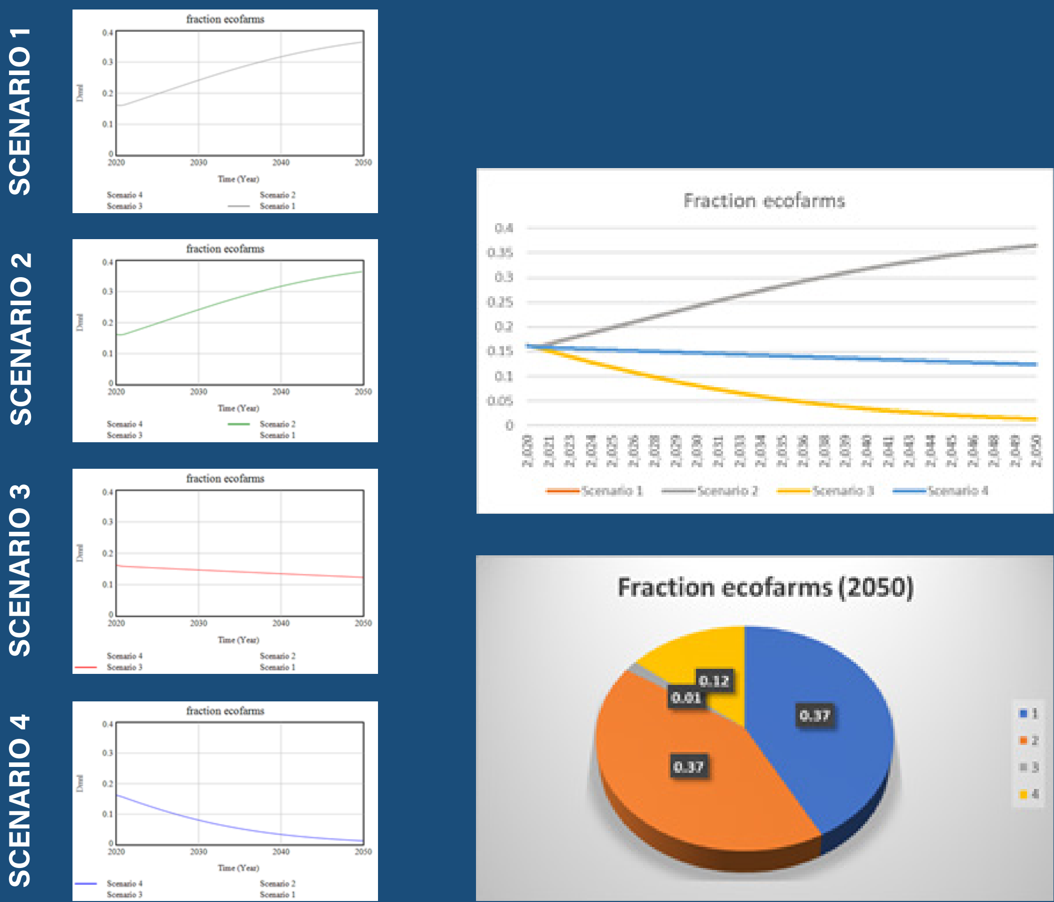

***Figure 12**: Fraction of ecofarms under different scenarios.*

KPI 13: IMPACT OF NITROGEN LOAD FROM AGRICULTURE

The "impact of nitrogen load from agriculture" is represented using the same methodology used for the calculation of the impact of nitrogen from aquaculture or tourism. Figure 13 shows that the lowest impact of the nitrogen load from agriculture is in Scenario 1 and Scenario 2, characterized by the highest value of the "Farm to Fork target" variable used in the model (0.30 or 0.25). The highest level of this KPI is reached in Scenario 4.

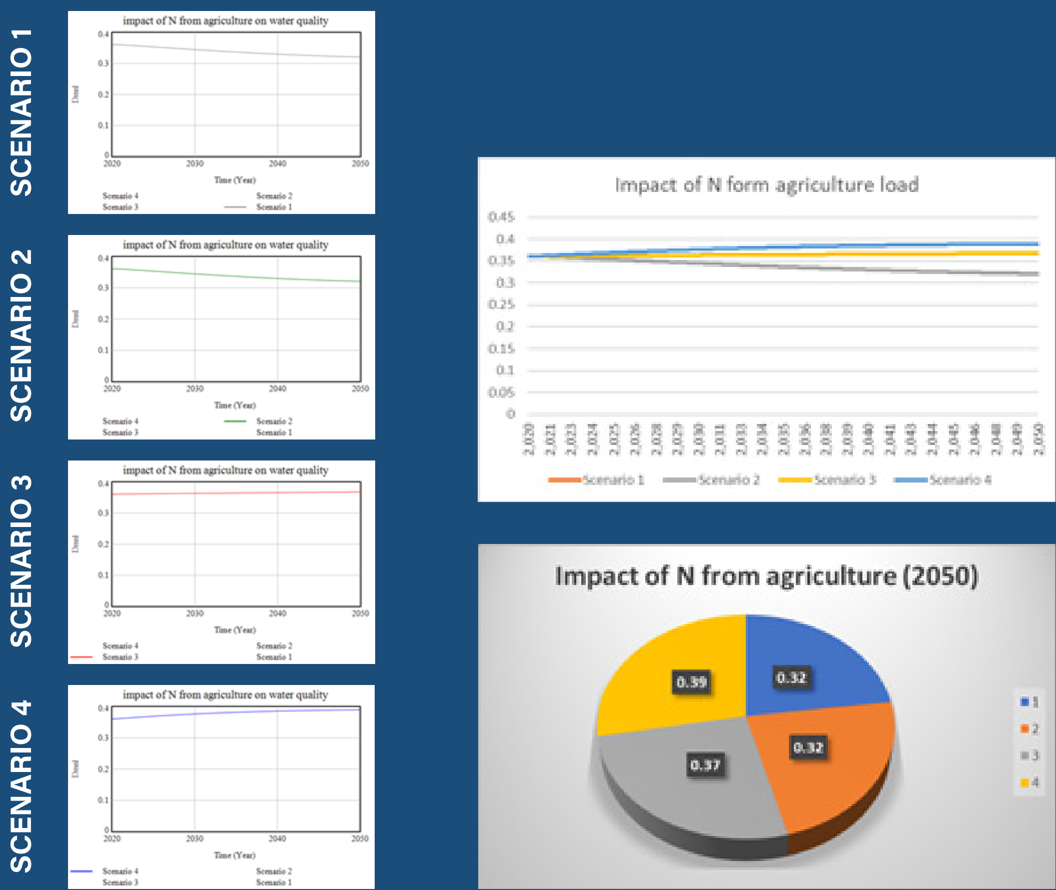

Figure 13*: Impact of nitrogen load from agriculture under different scenarios.*

CONCLUSION ABOUT THE OVERALL WATER QUALITY

One of the KPIs that links the three sub-models is "water quality", as it incorporates the cumulating pressures from different human activities, namely agriculture, tourism and aquaculture causing the introduction of nutrients[1] is the Danube's waters (see also Figure 14). In our case study, the lowest pressure is exerted by agriculture, which is reduced in the wetlands and the coastal zone. It can be concluded that the strategy of changing traditional farming practices into ecological farming reduces the impact in Scenarios 1 and 2. The transition to intensive fish farming, on the other hand, has the biggest impact on the Danube's water quality. The N-load is almost double in Scenario 4 and, in 2050, reaches a 12-16 folds higher N-load than agriculture. Finally, tourism, one of the most important activities in the Danube Delta and the Black Sea, has the same impact on the water quality in the longer term.

This implies that, when looking from the different perspectives, there is no ideal scenario including short-term benefits for all stakeholders. A sustainable development of the area needs important measures to reduce the environmental impact of human activities, while at the same time adding value and economic benefits for local communities (Figure 15).

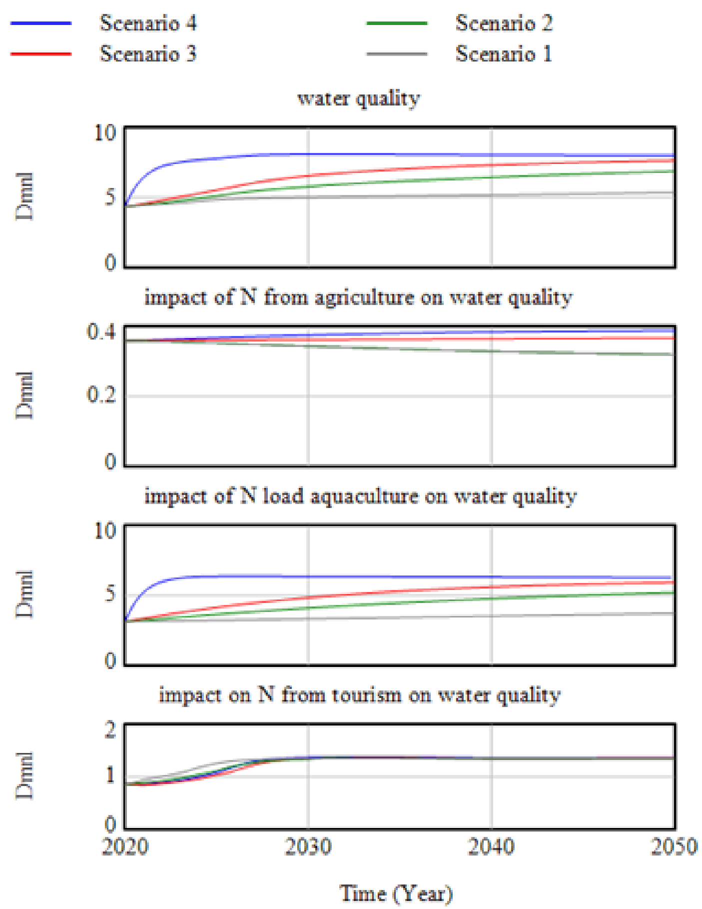

Figure 14: *Water quality causes strips under different scenarios.*

[1] COMMISSION DIRECTIVE (EU) 2017/845 of 17 May 2017 amending Directive 2008/56/EC (MSFD) of the European Parliament and of the Council as regards the indicative lists of elements to be taken into account for the preparation of marine strategies.

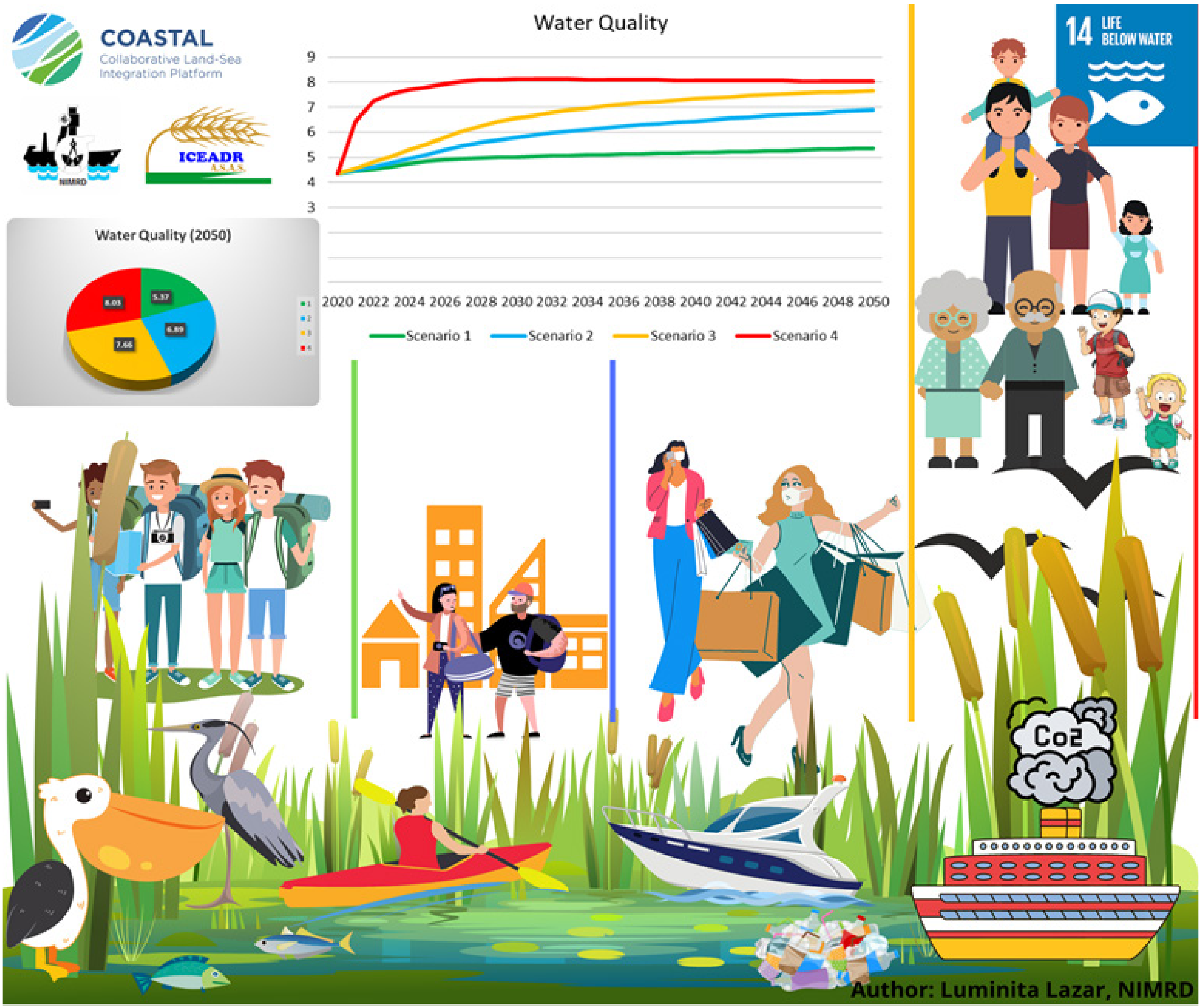

***Figure 15**: Infographic of the Danube's Mouths - Black sea water quality dynamics under different scenarios developed based on the shared socio-economic pathways (SSPs). From left to right: (1) Taking the Green Road, (2) Governance and Cooperation, (3) Inequity and (4) Fossil Fuels development.*

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SCENARIOS FOR THE MAR MENOR

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COASTAL
Collaborative Land-Sea Integration Platform

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CONTEXTUAL ELEMENTS INFLUENCING SCENARIO BUILDING

The regional government of Murcia and the Spanish national governmental institutes are currently elaborating on legislation and initiatives to support the conservation of the Mar Menor lagoon. Some of the scenarios that can be simulated with our SD model are extracted from the set of measures proposed by these authorities. Representatives of the responsible institutes have been involved in all project workshops. In addition to this, they were also interviewed to identify solutions and to characterize drivers important for the scenarios.

The outcomes of this research will be disseminated to several local, regional and national administrations, as well as to institutions from other sectors, such as farmer and tourism associations, local populations, regional development groups, etc. This will be done by means of a multi-actor workshop, the project web blog and dedicated publications. The project also intends to raise environmental and social awareness about the sectoral interlinkages that need to be accounted for when planning sustainable development scenarios. Especially the Regional Territorial Planning Department, the Regional Department for the Mar Menor lagoon, and the Segura River Watershed Authority showed great interest in knowing the final results of the project to try to integrate results into their current planning and management actions and to feed future development of legislation and Rural Development Programs.

STAKEHOLDER INVOLVEMENT DURING THE SCENARIO BUILDING PROCESS

PROJECT PARTNERS

Throughout the development process, local project partners were consulted to review the scenarios, and hence to correct and/or supplement them with additional information when needed. Representatives of the following organizations gave input for the scenarios:

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
FECOAM association	Farmers association	Agriculture	2	1	1	
CARM – General Directorate of Natural Environment (COASTAL actor partner)	Public Administration	Environment	2		2	
CARM - Regional Tourism Institute (directly linked to actor partner CARM)	Public Administration	Tourism	1	1		
CARM – Territorial Development Agency (directly linked to actor partner CARM)	Public Administration	Territorial development	1	1		
General Directorate of the Mar Menor (directly linked to actor partner CARM)	Public Administration	Environment	1		1	

OTHER STAKEHOLDERS

To cover the full width of the scope of the scenarios, also the following organizations were involved in the scenario building process:

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Independent consultant	Environmental SME	Agriculture and water management	1	1		
Independent consultant	Farming SME	Agricultural practices	1	1		
Fuente-Álamo Municipality	Public Administration	Environment	1	1		
ProAgua association	Farming SME	Agriculture, water quality & quantity	1	1		
Estación Nautica Mar Menor	Tourism SME	Tourism	1	1		
Fundación Nueva Cultura del AGUA	NGO	Sustainable development	1		1	
Universidad de Murcia	University	Nature conservation	1	1		
CSIC	Research institute	Watershed management	1		1	

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Universidad Politécnica de Cartagena	University	Photovoltaic energy	1	1		
Universidad de Murcia	University	Management of agricultural nutrients	1		1	

RATIONALE STAKEHOLDER SELECTION

The selection of stakeholders was based on the need to increase the legitimacy of the scenarios, as well as the necessity to involve more experts on the main topics included in the scenarios. As a result, representatives from the most relevant sectors in the study area were consulted, , such as tourism, environment, agriculture, water management, sustainable development, territorial planning, nutrients management, etc.

APPROACH

The scenarios were developed over the course of a year (May 2020 – July 2021) by means of desk research, email conversations, one-on-one meetings, telephone calls and discussions taking place in larger settings, such as workshops. The overview below gives a summary of the main meetings that took place in this course of events.

In addition to these meetings, part of the scenarios were also discussed in other meetings organized in the context of the COASTAL project, for instance in relation to the work that had to be done for WP3 (policy and business roadmaps) or WP4 (model development). The majority of the work, however, has been done by desk research, email consultation and conference calls due to the (severe) restrictions caused by the coronavirus pandemic.

1	Meeting with	FECOAM association
	When?	May 2020 and May 2021
	Main goal	We discussed the parts of the scenarios related to agricultural development and practices, costs and benefits.
2	Meeting with	Universidad de Murcia
	When?	November 2020
	Main goal	We discussed the parts of the scenarios related to agricultural nutrients and water balance.
3	Meeting with	ProAgua association
	When?	November and December 2020
	Main goal	We discussed the parts of the scenarios related to agricultural water sources and sustainable practices, the potential for agrivoltaics and agrotourism.
4	Meeting with	Independent Consultant
	When?	April 2020
	Main goal	We discussed the parts of the scenarios related to agricultural development and practices from the perspective of small farmers.

5	Meeting with	Independent consultant
	When?	May 2020
	Main goal	We discussed the parts of the scenarios related to water, nutrient management, climate change and agricultural development.
6	Meeting with	CARM – General Directorate of Natural Environment
	When?	May 2020
	Main goal	We discussed the parts of the scenarios related to governance and territorial planning of the study area.
7	Meeting with	Fundación Nueva Cultura del AGUA
	When?	December 2020
	Main goal	We discussed the parts of the scenarios related to governance, climate change and agricultural nutrients export.
8	Meeting with	CARM - Regional Tourism Institute
	When?	November 2020
	Main goal	We discussed the parts of the scenarios related to tourism development.
9	Meeting with	Several stakeholders/institutions
	When?	December 2020 (Second multi-actor workshop)
	Main goal	We showed and discussed the Shared Socioeconomic Pathways and provided the participants with a list of model variables that could be affected by them.

THE SCENARIOS IN RELATION TO THE MAR MENOR SD MODEL

As the scenarios for the Mar Menor deal with uncertainties external to the modelled system, they cannot be understood correctly without knowing the exact delineation of this system. What is 'in'? And what is 'out'? What is part of the modelled system? And what is not? This section therefore gives a brief introduction to the system dynamics model developed within COASTAL. Next, an overview is given of the uncertainties in the system's environment that were taken as a starting point to develop the scenarios.

WHAT DID WE MODEL?

The sustainable development of the Mar Menor coastal lagoon depends strongly on the balance and interactions between different sectors, such as inland agriculture, coastal tourism, salt pans and fisheries. The need to move towards sustainable modes of agriculture and tourism is increasingly recognized and has been revived over the past years due to a sudden increase in the coastal lagoon water contamination levels, which resulted in a strong drop in tourism. The system-dynamic model developed in COASTALin relation to MAL 6 aims to perform a holistic assessment that can help to identify solutions balancing the impacts on all sectors involved.

The model is based on the interactions and relations that were jointly identified with stakeholders during a series of sectoral and multisectoral workshops. Different model sectors are linked in the SD model and simulate dynamic interactions between the Campo de Cartagena catchment and the Mar Menor lagoon from 1961 until 2070. The model sectors are:

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

- **Agricultural nutrients balance**: This model sector quantifies the export of nutrients from irrigated agricultural areas to the Mar Menor lagoon based on the amount of fertilizer used. It allows to evaluate scenarios in relation to some potential end-of-pipe solutions that are in line with the current set of management actions proposed by regional and national authorities.

- **Sectoral development and economic profit**: This model sector reproduces the development of three main economic sectors involved, namely agriculture, tourism and solar photovoltaic energy production. The development of each sector is studied, together with the number of jobs created and its economic profit.

- **Mar Menor lagoon degradation**: This model sector simulates the ecological degradation of the Mar Menor lagoon over time following the input of nitrogen from agricultural sources, which was identified during the workshops as the main driver behind environmental degradation.

- **Coastal-rural recreation potential**: This model sector assesses the influence of the degradation of the Mar Menor on the coastal recreation potential, as well as the effect of increasing the rural and coastal recreation potential on the tourism sector.

- **Social awareness and governance**: Given the importance that stakeholders attributed to social environmental awareness and education, this model sector accounts for social and governance feedbacks in relation to the regulation and development of the different sectors in the study area.

- **Sustainable land management practices**: This model sector quantifies the benefits of implementing Sustainable Land Management practices, such as a decrease in fertilizer use and the creation of vegetation buffers around agricultural fields in order to prevent nutrient export and flooding.

(More detailed information about the model structure can be found in COASTAL Deliverable 14.)

WHAT KIND OF EXTERNAL UNCERTAINTIES WERE TAKEN INTO ACCOUNT?

As has been explained in the introductory part complementing this report, the Shared Socio-economic Pathways (SSPs), together with the Representative Concentration Pathways (RCPs), were used as a common starting point to develop the model-specific scenarios. In the table below, an overview is given of the parameters from this generic framework identified as being system external uncertainties that should be taken into account when assessing the behaviour of the system-dynamic model for the Mar Menor. The second column displays the input variables where the scenarios connect with the modelled system. The third column lists the parameters from the generic SSPs that were taken into consideration to explain the future evolution of these model-specific input variables.

N°	Model input variable	System-external uncertainties affecting this model input variable
1	Agricultural revenue per hectare	Relative prices of agricultural commodities Relative prices of agricultural inputs
2	Observed growth rate of agriculture	Export of agricultural commodities
3	Percentage of nutrients that are metabolized by the native lagoon ecosystem	Climate change severity
4	Average excess of fertilizer use	Environmental standards
5	Yearly effectiveness in nutrients reduction of nutrients, soil and water retention measures	Climate change severity
6	Electricity price	Electricity technology cost of renewables
7	Mean number of hours per day of photovoltaic electricity production	Technology development
8	Observed photovoltaic energy facilities growth rate in Megawatts installed	Energy technology change
9	Observed growth rate of tourism	Economic growth
10	Average percentage of groundwater desalinated	Environmental standards
11	Baseline for agricultural water demand per hectare	Climate change severity
12	Catchment water sources	Climate change severity
13	Urban wastewater treatment plant effluents	Population size
14	Yearly average of sea water desalination	Speed of agricultural technology development
15	Amount of water transferred from the Tagus river (RCP15ATS)	Climate change severity

DETAILED DESCRIPTION OF THE SCENARIOS

In total, we developed 4 scenarios for the Mar Menor. Each of them is rooted in the combination of a certain SSP with a climate scenario linked to a certain RCP. In addition to these scenarios, a Business As Usual scenario (BAU) is included by default. The latter is based on historical trends and values and is kept constant for comparative reasons. The BAU scenario is considered to include medium values in relation to the other scenarios. An overview can be found in this list:

- Scenario 1: SSP1 + RCP1.5
- Scenario 2: SSP2 + RCP1.5
- Scenario 3: SSP4 + RCP1.5
- Scenario 4: SSP5 + RCP1.5
- BAU: coincident with SSP2 but climate change is not considered

In the remaining part of this chapter the four scenarios for the Mar Menor are presented qualitatively based on a description of the input variables listed in the table on the previous page. The corresponding quantitative data can be found via this link to the online data repository. In summary, the process of downscaling the generic scenario framework that was used as a common starting point for the COASTAL regions to these region-specific descriptions of the model input variables, consisted of the following steps:

- In a first step, the qualitative descriptions of the SSP parameters relevant for each of the input variables were combined per scenario to get a better understanding of the relative magnitude of change at the level of the model's input variables.

- Next, reasonable minimum and maximum values were determined for each of the input variables during the period 2021-2070 based on scientific literature, interviews with stakeholders and expert knowledge.

- Finally, weighting factors were determined per scenario for each model variable as multipliers of the corresponding BAU values.

As a result, the quantitative descriptions of the input variables are (linear) increases or decreases of actual values towards reference BAU values multiplied by a weighting factor taking into account reasonable minimum and maximum values for each of these variables.

1. AGRICULTURAL REVENUE PER HECTARE

The agricultural revenue per hectare (EUR/ha) is positively influenced by the relative prices of agricultural commodities and negatively affected by the relative prices of agricultural inputs. The weighting factors of the BAU value (7,885 EUR/ha; (CHS, 2020) used for this variable are 0.5 and 1.25 for the minimum and maximum expected values, resulting in 3,942.5 EUR/ha and 9,856.25 EUR/ha, respectively.

SCENARIO 1

Both the relative prices of agricultural commodities and inputs are expected to be high in this scenario under SSP1 (Mitter et al., 2020). Since prices affecting production costs and benefits are supposed to increase, no significant net change is expected in the agricultural revenue per hectare, which remains equal to the BAU value.

SCENARIO 2

Both the relative prices of agricultural commodities and inputs are expected to be medium in this scenario under SSP2 (Mitter et al., 2020), so no significant change is expected in the agricultural revenue per hectare, which remains equal to the BAU value.

SCENARIO 3

The relative prices of agricultural commodities are expected to be medium and the relative prices of agricultural inputs are expected to be high under SSP4 (Mitter et al., 2020), so the agricultural revenue per hectare is expected to decrease. Consequently, the model considers a linear decrease in the value of this variable from the BAU to the minimum value for the simulation period between 2021-2070.

SCENARIO 4

The relative prices of agricultural commodities are expected to be medium and the relative prices of agricultural inputs are expected to be low under SSP5 (Mitter et al., 2020), so the agricultural revenue per hectare is expected to increase. Therefore, the model considers a linear increase in the value of this variable from the BAU to the maximum value for the simulation period (2021-2070).

2. GROWTH RATE AGRICULTURE

The observed growth rate of agriculture (annual %) is positively influenced by the export of agricultural commodities. The weighting factors of the BAU value (7%; (Carreño et al., 2015)) used for this variable are 0.5 and 2 for the minimum and maximum expected values, resulting in 3.5% and 14%, respectively.

SCENARIO 1

The export of agricultural commodities is expected to be low under SSP1 (Mitter et al., 2020), so the observed growth rate of agriculture is expected to decrease. Consequently, the model considers a linear decrease in the value of this variable from the BAU to the minimum value.

SCENARIO 2

The export of agricultural commodities is expected to be medium under SSP2 (Mitter et al., 2020), so no significant change is expected in the observed growth rate of agriculture, which remains on the BAU value.

SCENARIOS 3 & 4

The export of agricultural commodities is expected to be high under SSP4 and SSP5 (Mitter et al., 2020), so the observed growth rate of agriculture is expected to increase. Therefore, the model considers a linear increase in the value of this variable from the BAU to the maximum value.

3. NUTRIENTS METABOLIZED BY THE NATIVE LAGOON SYSTEM

The percentage of nutrients that are metabolized by the native lagoon ecosystem (annual %) is negatively influenced by the severity of climate change, given that the water temperature is expected to increase, which negatively impacts coastal lagoon ecological processes (Comité de Asesoramiento Científico del Mar Menor, 2017). The weighting factors of the BAU value (20 %; (Comité de Asesoramiento Científico del Mar Menor, 2017)) used for this variable are 0.75 and 1.25 for the minimum and maximum expected values under mild climate change scenarios, resulting in 15% and 25% respectively.

SCENARIOS 1, 2, 3 & 4

Climate change severity is expected to be higher than current conditions under RCP 1.5, so the percentage of nutrients that are metabolized by the native lagoon ecosystem is expected to decrease. Therefore, the model considers a linear decrease in the value of this variable from the BAU to the minimum value.

4. AVERAGE EXCESS OF FERTILIZER USE

The average excess of fertilizer use (Kg/ha) is negatively influenced by increasing environmental standards. The weighting factors of the BAU value (40 Kg/ha; (TRAGSATEC, 2019)) used for this variable are 0.5 and 1.5 for the minimum and maximum expected values, resulting in 20 Kg/ha and 60 Kg/ha respectively.

SCENARIO 1

Environmental standards are expected to be high under SSP1 (Mitter et al., 2020), so the average excess of fertilizer use is expected to decrease. Therefore, the model considers a linear decrease in the value of this variable from the BAU to the minimum value.

SCENARIO 2

Environmental standards are expected to be medium under SSP2 (Mitter et al., 2020), so no significant change is expected in the average excess of fertilizer use, which remains on the BAU value.

SCENARIOS 3 & 4

Environmental standards are expected to be low under SSP4 and SSP5 (Mitter et al., 2020), so the average excess of fertilizer use is expected to increase. Therefore, the model considers a linear increase in the value of this variable from the BAU to the maximum value.

5. NUTRIENTS REDUCTION DUE TO NUTRIENTS, SOIL AND WATER (NSW) RETENTION MEASURES

The yearly effectiveness in nutrients reduction due to NSW retention measures (annual %) is negatively influenced by the severity of climate change, given that extreme events are expected to increase (Pärn et al., 2012). The weighting factors of the BAU value (70 %; (Pärn et al., 2012) used for this variable are 0.75 and 1.25 for the minimum and maximum expected values under mild climate change scenarios, resulting in 52.5 % and 87.5 % respectively.

SCENARIOS 1, 2, 3 & 4

Climate change severity is expected to be higher that current conditions under RCP 1.5, so the yearly effectiveness in nutrients reduction of NSW retention measures is expected to decrease. Therefore, the model considers a linear decrease in the value of this variable from the BAU to the minimum value.

6. ELECTRICITY PRICE

The electricity price (EUR/Kw*hour) is positively influenced by the electricity technology cost of renewables. The weighting factors of the BAU value (0.05 EUR/Kw*hour; (APPA, 2018) used for this variable are 0.5 and 2 for the minimum and maximum expected values, resulting in 0.025 EUR/Kw*hour and 0.1 EUR/Kw*hour, respectively.

SCENARIOS 1 & 3

The electricity technology cost of renewables is expected to be low under SSP1 and SSP4 (Calvin et al., 2017), so the electricity price is expected to decrease. Consequently, the model considers a linear decrease in the value of this variable from the BAU to the minimum value.

SCENARIOS 2 & 4

The electricity technology cost of renewables is expected to be medium under SSP2 and SSP5 (Calvin et al., 2017), so no significant change is expected in the electricity price, which remains on the BAU value.

7. PHOTOVOLTAIC ELECTRICITY PRODUCTION

The mean number of hours per day of photovoltaic electricity production (hours/day) is positively influenced by technology development. The weighting factors of the BAU value (5 hours/day; (APPA, 2018) used for this variable are 0.5 and 2 for the minimum and maximum expected values, resulting in 2.5 hours/day and 10 hours/day respectively.

SCENARIOS 1, 3 & 4

Technology development is expected to be higher than today under SSP1, SSP4 and SSP5 (O'Neill et al., 2017), so the mean number of hours per day of photovoltaic electricity production is expected to increase. Consequently, the model considers a linear increase in the value of this variable from the BAU to the maximum value.

SCENARIO 2

Technology development is expected to be medium under SSP2 (O'Neill et al., 2017), so no significant change is expected in the mean number of hours per day of photovoltaic electricity production, which remains on the BAU value.

8. PHOTOVOLTAIC ENERGY FACILITIES GROWTH RATE

The observed photovoltaic energy facilities growth rate in Megawatts installed is positively influenced by energy technology change. The weighting factors of the BAU value (1.6 %/year; (ECONET, 2020a) used for this variable are 0.5 and 3 for the minimum and maximum expected values, resulting in 0.8 %/year and 4.8 %/year respectively.

SCENARIO 1

Energy technology change is expected to be high under SSP1 (O'Neill et al., 2017), so the observed photovoltaic energy facilities growth rate in Megawatts installed is expected to increase. Consequently, the model considers a linear increase in the value of this variable from the BAU to the maximum value.

SCENARIOS 2 & 3

Energy technology change is expected to be medium under SSP2 and SSP4 (O'Neill et al., 2017), so no significant change is expected in the observed photovoltaic energy facilities growth rate in Megawatts installed, which remains on the BAU value.

SCENARIO 4

Energy technology change is expected to be low under SSP5 (O'Neill et al., 2017), so the observed photovoltaic energy facilities growth rate in Megawatts installed is expected to decrease. Consequently, the model considers a linear decrease in the value of this variable from the BAU to the minimum value.

9. GROWTH RATE TOURISM

The observed growth rate of tourism is positively influenced by economic growth. The weighting factors of the BAU value (3 %/year; (ECONET, 2020b)) used for this variable are 0.5 and 2 for the minimum and maximum expected values, resulting in 1.5 %/year and 6 %/year respectively.

SCENARIOS 1, 2 & 3

Economic growth is expected to be medium under SSP1, SSP2 and SSP4 (O'Neill et al., 2017), so no significant change is expected in the observed growth rate of tourism, which remains on the BAU value.

SCENARIO 4

Economic growth is expected to be high under SSP5 (O'Neill et al., 2017), so the observed growth rate of tourism is expected to increase. Consequently, the model considers a linear increase in the value of this variable from the BAU to the maximum value.

10. GROUNDWATER DESALINATED

The average percentage of groundwater that becomes desalinated is negatively influenced by environmental standards. The weighting factors of the BAU value (50%; personal communication during expert interviews) used for this variable are 0.5 and 2 for the minimum and maximum expected values, resulting in 25% and 100% respectively.

SCENARIO 1

Environmental standards are expected to be high under SSP1 (Mitter et al., 2020), so the average percentage of groundwater desalinated is expected to decrease. Consequently, the model considers a linear decrease in the value of this variable from the BAU to the minimum value.

SCENARIO 2

Environmental standards are expected to be medium under SSP2 (Mitter et al., 2020), so no significant change is expected in the average percentage of groundwater desalinated, which remains on the BAU value.

SCENARIO 3 & 4

Environmental standards are expected to be low under SSP4 and SSP5 (Mitter et al., 2020), so the average percentage of groundwater desalinated is expected to increase. As a consequence, the model considers a linear increase in the value of this variable from the BAU to the maximum value.

11. AGRICULTURAL WATER DEMAND PER HECTARE

The baseline for agricultural water demand per hectare (Hm3/hectare*year) is positively influenced by the severity of climate change, given that the mean annual temperature is expected to increase (Masson-Delmotte et al., 2021). The weighting factors of the BAU value (0.004 Hm3/hectare*year; (TRAGSATEC, 2019)) used for this variable are 0.75 and 1.25 for the minimum and maximum expected values under mild climate change scenarios, resulting in 0.003 Hm3/hectare*year and 0.005 Hm3/hectare*year respectively.

SCENARIOS 1, 2, 3 & 4

Climate change severity is expected to be higher than current conditions under RCP 1.5, so the baseline for agricultural water demand per hectare is expected to increase. Consequently, the model considers a linear increase in the value of this variable from the BAU to the maximum value.

12. CATCHMENT WATER SOURCES

The factor 'Catchment water sources' (Hm3/year) is negatively influenced by the severity of climate change, given that extreme events (droughts and heat waves) are expected to increase and overall precipitation to decrease (Masson-Delmotte et al., 2021). The weighting factors of the BAU value (11 Hm3/year; (TRAGSATEC, 2019)) used for this variable are 0.75 and 1.25 for the minimum and maximum expected values under mild climate change scenarios, resulting in 8.25 Hm3/year and 13.75 Hm3/year respectively.

SCENARIOS 1, 2, 3 & 4

The impacts of climate change are expected to be higher than today under RCP 1.5, so catchment water sources are expected to decrease due to the occurrence of higher temperatures and lower precipitation levels (Masson-Delmotte et al., 2021). Consequently, the model considers a linear decrease in the value of this variable from the BAU to the minimum value.

13. URBAN WASTEWATER TREATMENT PLANT EFFLUENTS

Urban wastewater treatment plant effluents (Hm3/year) are positively influenced by population growth. The weighting factors of the BAU value (29.8 Hm3/ year; (TRAGSATEC, 2019)) used for this variable are 0.5 and 2 for the minimum and maximum expected values under mild climate change scenarios, resulting in 14.9 Hm3/ year and 59.6 Hm3/ year respectively.

SCENARIOS 1, 2 & 3

Population growth is expected to be medium under SSP1, SSP2 and SSP 4 (Mitter et al., 2020), so no significant changes are expected in urban wastewater treatment plant effluents, which remains on the BAU value.

SCENARIO 4

Population size is expected to be high under SSP5 (Mitter et al., 2020), so urban wastewater treatment plant effluents are expected to increase. Consequently, the model considers a linear increase in the value of this variable from the BAU to the maximum value.

14. SEAWATER DESALINATION

The factor 'Yearly average of sea water desalination' is positively influenced by the speed of agricultural technology development. The weighting factors of the BAU value (8.2 Hm3/ year; (TRAGSATEC, 2019)) used for this variable are 0.5 and 2 for the minimum and maximum expected values under mild climate change scenarios, resulting in 4.1 Hm3/ year and 16.4 Hm3/ year respectively.

SCENARIOS 1, 3 & 4

The speed of agricultural technology development is expected to be higher than today under SSP1, SSP4 and SSP5 (Mitter et al., 2020), so the yearly average of sea water desalination is expected to increase. Consequently, the model considers a linear increase in the value of this variable from the BAU to the maximum value.

SCENARIO 2

The speed of agricultural technology development is expected to be medium under SSP2 (Mitter et al., 2020), so no significant change is expected in the yearly average of sea water desalination, which remains on the BAU value.

15. WATER TRANSFERRED FROM THE TAGUS

The amount of water transferred from the Tagus river is negatively influenced by the severity of climate change (Pellicer-Martínez and Martínez-Paz, 2018). The weighting factor of the BAU value (330 Hm3/ year; (Morote et al., 2017)) used for this variable is 0.75 for the minimum expected value under mild climate change scenarios (no maximum expected value was considered in this case), resulting in 247.5 Hm3/ year.

SCENARIOS 1, 2, 3 & 4

The impacts of climate change are expected to be more severe than today under RCP 1.5, so the amount of water transferred from the Tagus river is expected to decrease. Consequently, the model considers a linear decrease in the value of this variable from the BAU to the minimum value.

COMPARISON OF THE DYNAMIC PATTERNS OF KEY MODEL VARIABLES

The main question answered in this chapter is: How do changes in the modelled system's environment impact the functioning of this system, and hence the patterns of key variables? To investigate this, the model has been run under each of the scenarios presented in the previous chapter while no (policy) measures have been taken within the system itself. Or said in other words: the input variables foreseen in the model to structurally change the system itself are kept in a status corresponding with the system's condition year 2021. Only input variables representing external uncertainties influencing the system's behavior, that is the variables through which each of the scenarios can be 'turned on', were feeding the model.

The Mar Menor model has different key performance indicators (KPI) in relation to several social, economic and environmental aspects. We will focus here on the ones most affected by the identified external uncertainties, such as the amount of agricultural nutrients in the Mar Menor lagoon, the amount of brine produced, the total number of jobs, the total gross economic benefit, the amount of irrigated land areas, the potential photovoltaic energy power installed and the agricultural pressure on water resources.

KPI 1: BRINE PRODUCED

The amount of brine produced (Figure 1) depends, among other things, on the average percentage of groundwater that becomes desalinated. Scenarios 3 and 4 show the same pattern with a steady increase reaching the highest values, followed by scenario 2, which has a much lower production of brine. The BAU scenario reaches a maximum value around 2060, which is lower than in scenario 2 and remains constant. Finally, scenario 1 shows the lowest values, with a peak around 2050, after which the production starts decreasing. Without extra measures taken within the system to lower the amount of brine production, scenario 1 is the most favorable for this KPI.

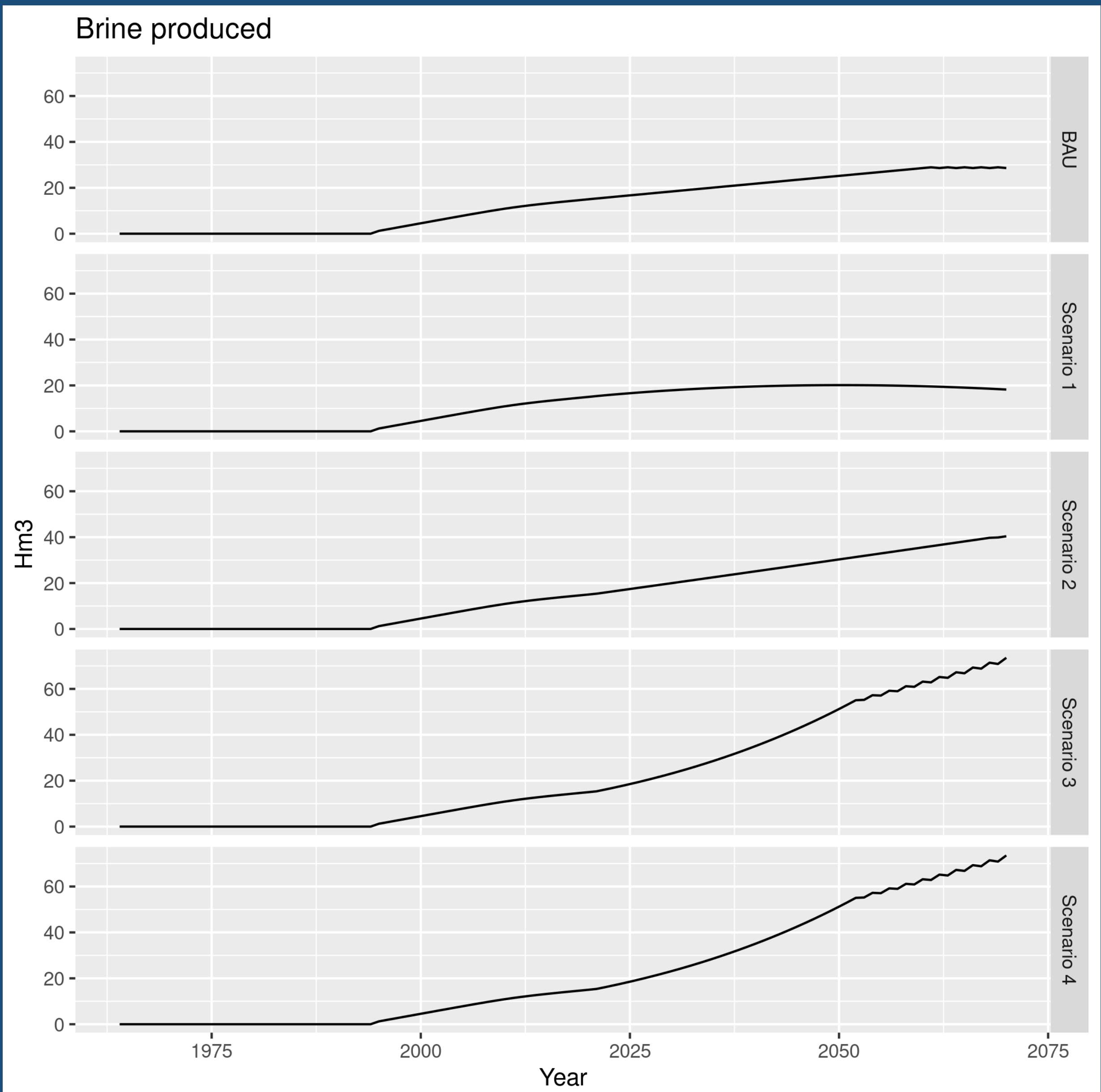

Figure 1: Brine produced under the different scenarios

KPI 2: AGRICULTURAL NUTRIENTS IN THE MAR MENOR LAGOON

The amount of agricultural nutrients in the Mar Menor lagoon (Figure 2) is the result of a balance between the nitrate consumed by the lagoon metabolism and the agricultural nutrient input (influenced by, among other things, the amount of brine produced, the average excess of fertilizer use, the yearly effectiveness in nutrient reduction, soil and water retention measures, etc.). Scenarios 3 and 4 show the same pattern with a steady increase reaching the highest values, followed by scenario 2, showing much lower values. The BAU scenario reaches a maximum value around 2060, which is lower than in scenario 2. Finally, scenario 1 shows the lowest values, with a peak around 2050, after which it starts decreasing. Without extra measures taken within the system to lower the amount of nutrients input to the Mar Menor, scenario 1 is the most favorable for this KPI.

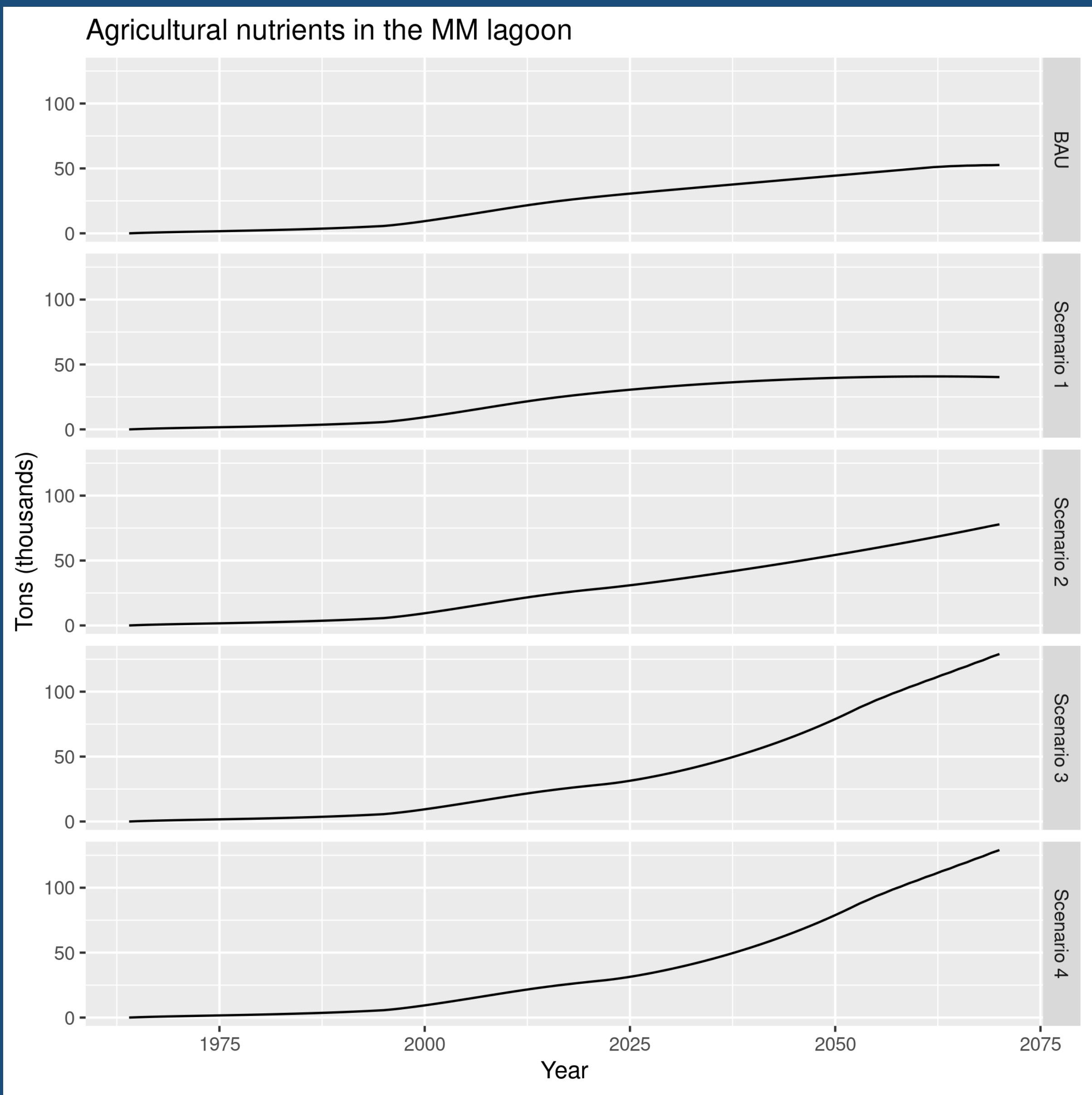

Figure 2: Agricultural nutrients in the Mar Menor lagoon under different scenarios

KPI 3: IRRIGATED LAND AREA

The area of irrigated farmland (Figure 3) depends, among other things, on the growth rate of agriculture. Scenarios 3 and 4 show the same linear increase, which reaches the maximum potential value shortly after 2050. This means that all farmland will be irrigated by then, including new developed areas that were previously not farmland. The BAU scenario shows a similar pattern, though with a few years delay. The same applies for scenario 2, notwithstanding this delay is more explicit under this scenario. Only under scenario 1 one can assume that, without extra (policy) measures taken within the system, the area of irrigated farmland will remain more or less similar to the current values.

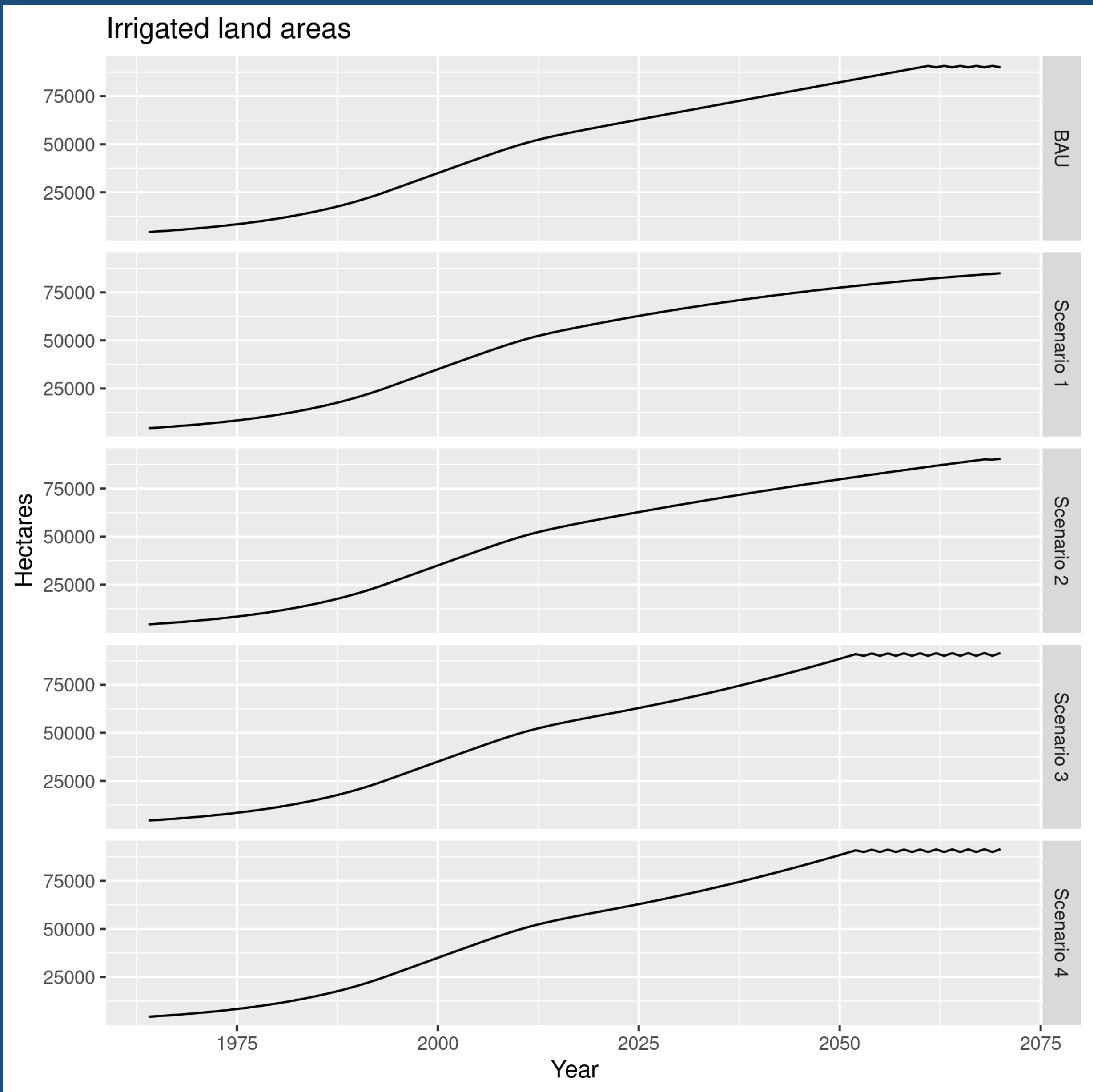

Figure 3: Area with irrigated land under different scenarios

KPI 4: AGRICULTURAL PRESSURE ON WATER RESOURCES

The pressure on water resources from agricultural water use (Figure 4) is a ratio between the available surface water for agriculture, which depends on, among other things, catchment water sources, urban wastewater treatment plant effluents, yearly average sea water desalination and the amount of water transferred from the Tagus river, and the total agricultural water demand. The latter is a product of the area of irrigated farmland and cropland water requirements. Scenarios 3 and 4 display the same pattern showing a gradual increase until around 2050 and a stagnation afterwards. The same pattern is found under the BAU scenario, though with a delay. Scenarios 2 and 1 show the highest and second highest values, respectively, both following a gradual increase that eventually ends up higher than under the other 3 scenarios. Without extra measures taken within the system to lower the agricultural water demand, no scenario is favorable for this KPI.

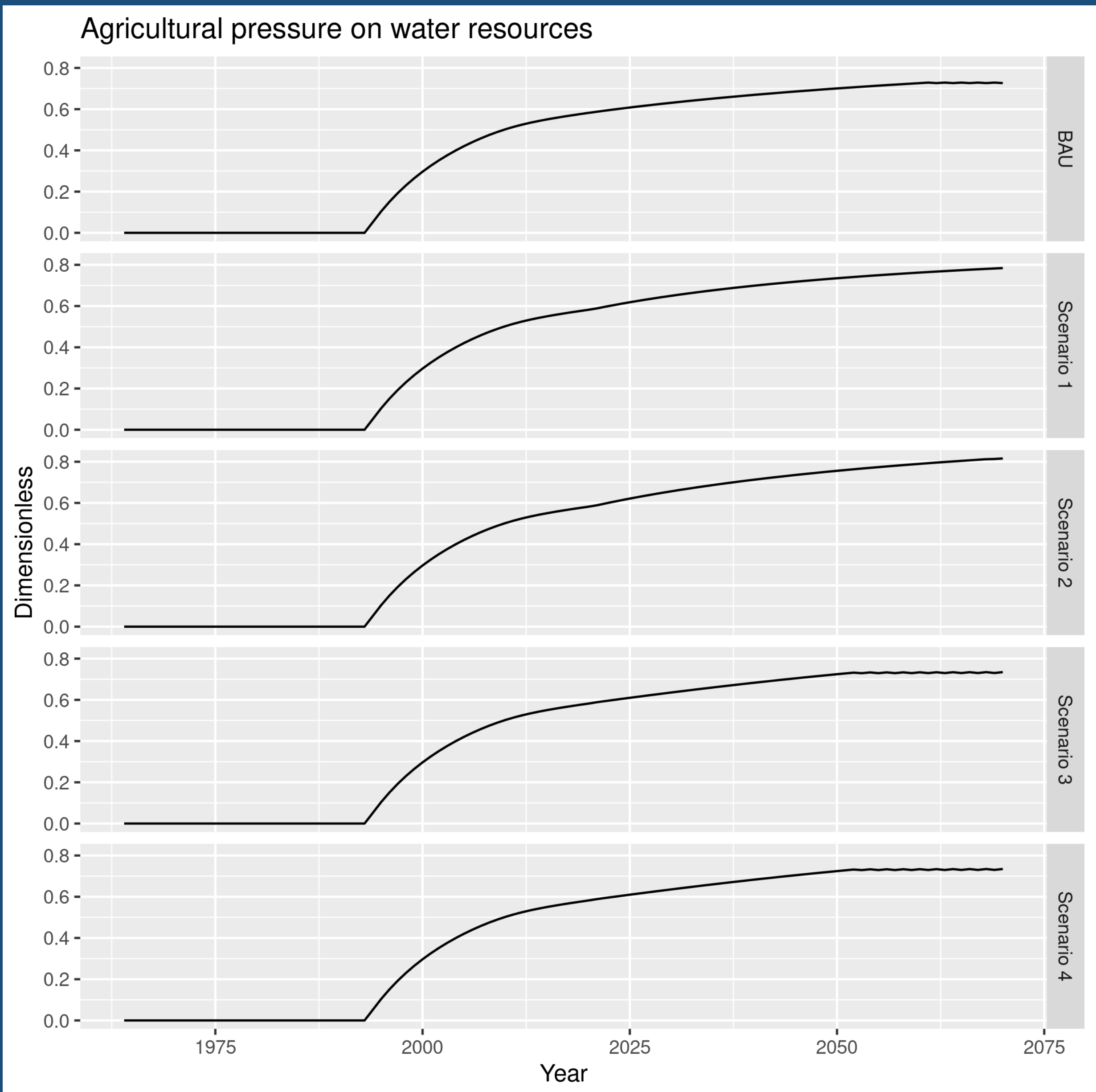

Figure 4: Agricultural pressure on water resources under different scenarios

KPI 5: PHOTOVOLTAIC ENERGY FACILITIES INSTALLED

The number of photovoltaic Megawatts installed (Figure 5) depends, among other things, on the observed photovoltaic energy growth rate. The model only shows values starting in 2020 as there are no older data for this variable. Scenario 1 shows an exponential increase reaching the highest values, whereas scenario 4 shows a rather small linear increase. The BAU scenario, together with scenarios 2 and 3, show the same increasing values and a slightly exponential pattern. Without extra measures taken within the system to increase photovoltaic energy, scenario 1 is the most favorable for this KPI.

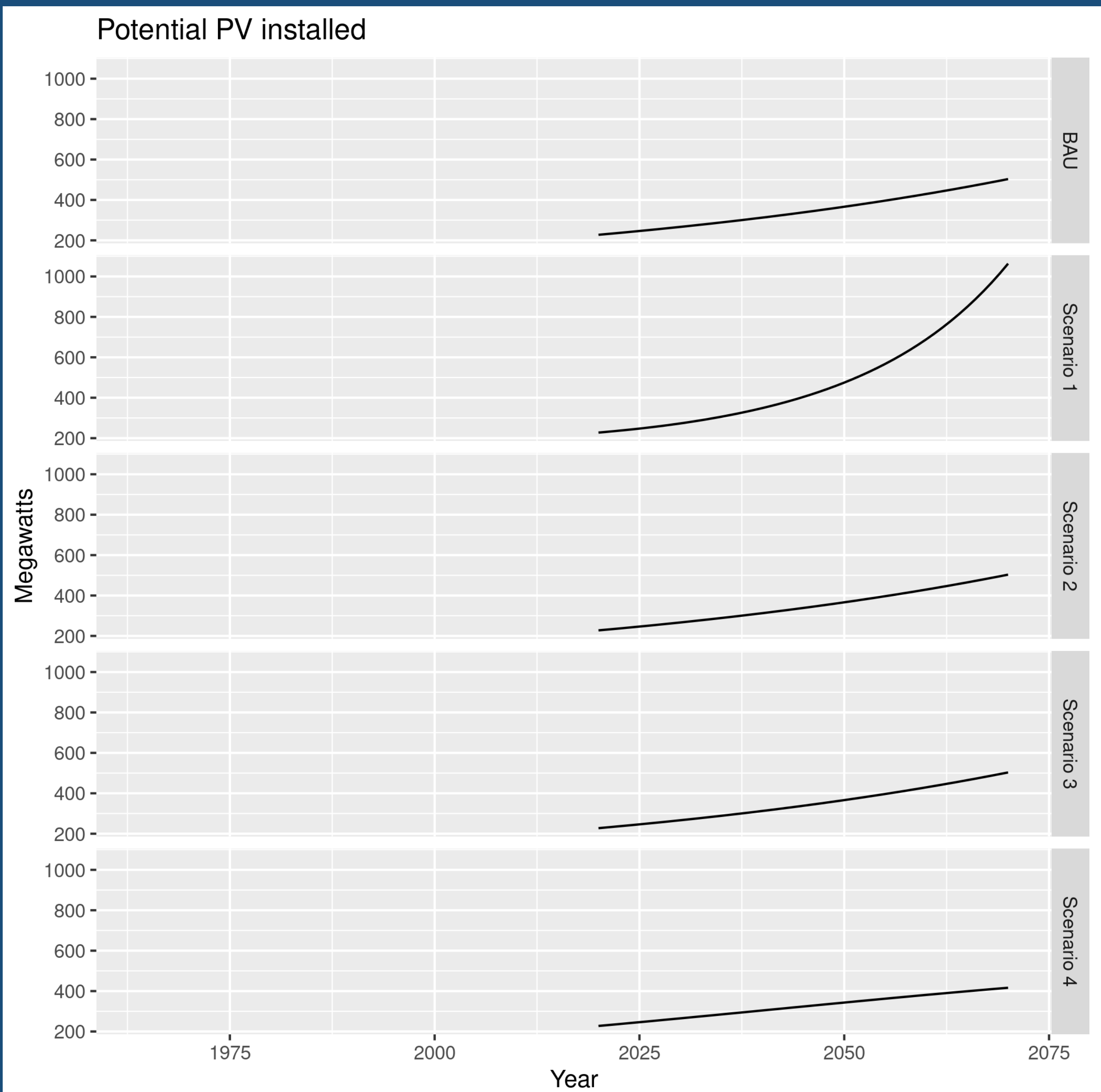

Figure 5: Photovoltaic energy facilities (MW) installed under different scenarios

KPI 6: TOTAL NUMBER OF JOBS

The total number of jobs (Figure 6) depends in the SD model on the number of jobs created in the photovoltaic, agricultural and tourism sector. The model shows results starting from the year 2000, which is the earliest date from which we have tourism data. For the photovoltaic sector our data only go back to the year 2020. Before the year 2000, the model therefore only considers the number of jobs in the agricultural sector.

From 2000 until shortly after 2020 the steep increase in all scenarios is mostly due to the rapid development of the tourism. Scenarios 3 and 4 show almost identical results: first a steep increase, followed by a slightly exponential curve, showing a peak with the highest value after 2050. After 2050 the curve gradually decreases towards 2070. The BAU scenario closely follows the previous pattern, but shows a slight time delay and does not reach such a high peak. The curve under scenario 2 shows a more gradual increase and reaches a peak before 2027. Finally, scenario 1 shows a gradual increase with a steady growth during the study period (2021-2070). Without extra measures taken within the system to increase the number of jobs, scenario 1 is the most favorable for this KPI, given that it shows an increasing trend in 2070.

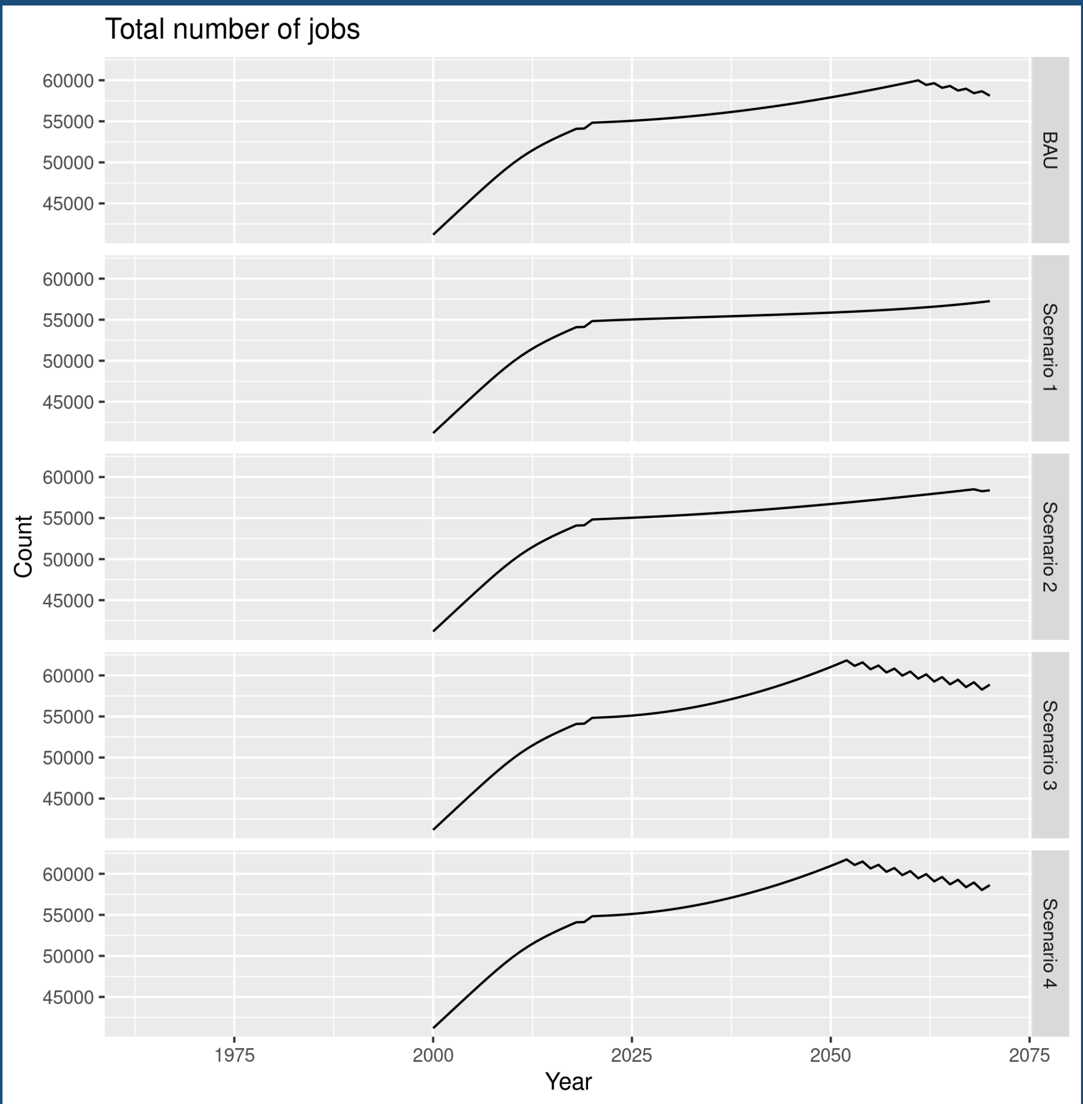

Figure 6: Total number of jobs under different scenarios

KPI 7: GROSS ECONOMIC BENEFIT

The total gross economic benefit (Figure 7) depends on the yearly gross economic benefit of the photovoltaic, agricultural and tourism sectors. Several variables therefore play an indirect role, such as agricultural revenue per hectare, electricity price, mean number of hours per day of photovoltaic electricity production and observed growth rate of tourism. Initially, the curves display the same pattern as observed in the curves of the previous KPI. However, they are followed by contrasting trajectories for the different scenarios. Scenario 4 reaches the highest total gross economic benefit, whereas scenario 3 shows the lowest values. The BAU scenario, together with scenarios 1 and 2 show similar values but the final decreasing trend in scenario 1 is less steep than in the other curves. Without extra measures taken within the system to increase the total gross economic benefit, scenario 4 is the most favorable for this KPI.

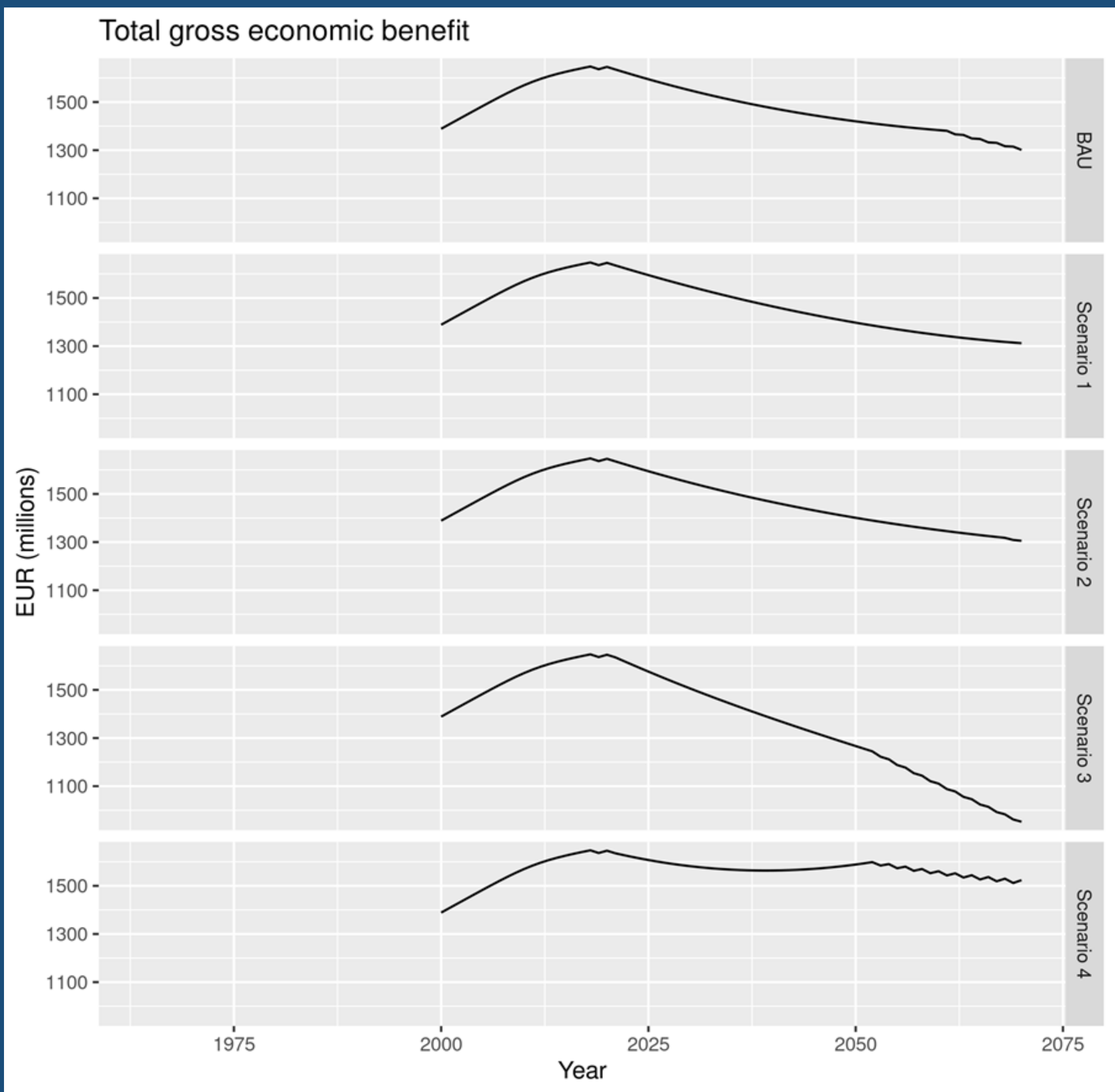

Figure 7: Gross economic benefit under different scenarios

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SCENARIOS FOR THE NORRSTRÖM - BALTIC AREA

Seifollahi, S., Vigouroux, G., Destouni, G. and D'Haese, N.

COASTAL
Collaborative Land-Sea Integration Platform

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CONTEXTUAL ELEMENTS INFLUENCING SCENARIO BUILDING

The process of System Dynamics (SD) modelling and its quantification for the Norrström - Baltic Sea case creates a holistic understanding of the water-related problems in the area, as well as the climate and socio-economic implications for different sectors. The model also supports communication and dissemination activities to relevant stakeholders. The SD model is structured based on a causal loop diagram (CLD) co-created with local and regional stakeholders from various land-, coast-, and sea-based sectors. It evaluates water availability and quality interactions among key sectors, natural water sub-systems and hydro-climatic system components. The sectors that were taken into consideration include agriculture, forestry and natural ecosystems, inland and coastal municipal water, wastewater utilities and industry. Model-related analysis focuses on sectoral water availability and quality, seawater intrusion risks to fresh coastal groundwater, coastal nutrient loading and eutrophication, as these parameters reflect the impacts of hydro-climatic changes and sectoral activities in this region. As a consequence, regional water authorities and relevant companies have been involved in various project workshops, including:

- Stockholm Vatten Och Avfall – operates and develops water and wastewater services;
- Swedish Agency of Marine and Water Management (Hav) – government agency responsible for protecting, restoring and ensuring sustainable use of freshwater resources and seas including fisheries management; and
- Water Centre for Innovation as part of a municipality in the region – provides advisory service to private sectors for local water management and leads innovation projects on small-scale drinking water and wastewater solutions.

Some of the scenarios used to validate the model are defined based on key drivers behind regional development that were proposed by stakeholder representatives from these authorities. Potential business and policy solutions to promote land-sea synergies and coastal sustainability were also prioritized together with representatives from regional water authorities (including the ones mentioned above), industrial companies and business organizations for green sectors.

The outcomes of these analyses will be disseminated to regional and national administrations, spatial planning and development authorities, as well as a broader network of stakeholders from other sectors (e.g. tourism associations and academia) who are currently collaborating with Stockholm University (SU). SU has also been active in conference presentations and open-access publications based on the project outcomes that support further communication of the developed SD model and its results to potential end-users.

Furthermore, model-based analysis in the Norrström - Baltic region has developed a holistic understanding of system behaviour, sea-based feedback mechanisms to coastal areas, and the necessity of cross-scale and multi-sectoral management strategies for coastal water quality improvement. Such understanding has been acknowledged by the stakeholders and needs to be accounted for in regional coastal planning and management.

The scenarios presented in this report are developed based on projected climate and socio-economic changes, following the representative concentration pathways (RCPs) and the shared socio-economic pathways (SSPs) for the region. These scenarios along with the model validation scenarios proposed by the stakeholders will be summarized in a digital flipbook to be published on the project webpage and distributed among relevant authorities and administrations. This flipbook will provide a comprehensive insight on potential future changes and their impacts on sectoral activities and water systems, and can further support regional planning and coastal water management by responsible authorities.

STAKEHOLDER INVOLVEMENT DURING THE SCENARIO BUILDING PROCESS

PROJECT PARTNERS

The key land-sea interactions between main system components, SD model development and quantification, as well as the change/development scenarios for model validation and testing, were developed in close collaboration with local and regional project partners. Preliminary results were shared and discussed with them in the second multi-actor workshop (cfr. WP1). The table below gives a more detailed view of these organisations:

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Water Centre for Innovation - Campus Roslagen (CRAB)	municipality-based knowledge center	Water & wastewater treatment	2		2	
Global Utmaning (GLOB)	Independent think tank non-profit association	Sustainable development under global challenges	3	2	1	
Stockholm Environment Institute (SEI)	International non-profit research and policy organization	Agriculture and food production, water management, capacity building, and national strategy development in relation to environmental challenges	3	1	2	
Niras Sweden AB (NIRAS)	Consulting industry firm	Building infrastructure, energy, utilities, and environment in industry and urban planning	1	1		
Natural Resources Institute (LUKE) - Finland	Research institute	Natural resources and aquatic ecosystems management, sustainable development, and bio-economy	2	1	1	

OTHER STAKEHOLDERS

In order to cover all needed expertise, also other local and regional stakeholders were involved in the sector and multi-actor workshops. Their details are summarized in the table below.

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Stockholm Vatten Och Avfall	Water and waste management company	Water and wastewater utilities and management	2	1	1	
The Federation of Swedish Farmers (LRF)	Farmers association	Green growth, agriculture and food production, cultivation, drainage, and fertility	1	1		
Swedish Agency of Marine and Water Management (Hav)	Government agency	Sustainable use of freshwater resources and seas including fisheries management	1		1	
The Royal Swedish Academy of Engineering Sciences (IVA)	Engineering science organization	Human societies, new digital technologies and innovative technical solutions	1	1		
KTH Royal Institute of Technology	Research institute	Urban and energy planning	1		1	
Swedish University of Agricultural Sciences (SLU)	Research institute	Aquaculture, and aquatic ecosystem health management	1	1		
The Royal Swedish Academy of Agriculture and Forestry (KSLA)	Research institute	Agriculture and forestry, environmental management, blue mussel farming and sustainability	2		2	
Satakunta University of Applied Sciences	Research institute	Water management, smart urban and business development, and maritime cluster	1		1	

RATIONALE STAKEHOLDER SELECTION

The list with potential participants was developed within the networks of the case lead and local partners following the snowball method (Biernacki and Waldorf 1981). The aim of this process was to identify key actors with relevant expertise and/or having the authority to influence, or contribute to, coastal and environmental development in the Norrström-Baltic area. The list ultimately consisted of, in total, 112 relevant organizations and included green industry actors with agricultural and forestry backgrounds, municipalities, spatial planning actors, blue industry actors, research organizations, businesses, NGOs and regional authorities. Each of them is affected by and/or contributes to the regional water-related issues and associated challenges to inland, coastal and marine environments. For each organization at least one person with relevant responsibilities, activities, expertise and practical experience was involved. Some actors were even involved in more than one workshop based on the relevance of their expertise. Besides these third parties, also the local project partners participated in the workshops. The reason to involve this selection of stakeholders was to increase the uptake of the project's outcomes by appropriate local and regional end-users.

APPROACH

A first version of the change and development scenarios for the Norrström - Baltic region was developed and analyzed in the period between April and October 2020. These scenarios were shared and discussed with the stakeholders and local project partners during the second multi-actor workshop (20th of November 2020 – an online meeting due to COVID restrictions) and further updated in the period between January and March 2021 based on their feedback. However, based on the discussions that took place during the workshops organized for WP3 (Business and policy roadmaps) and WP5 (Scenarios and transition pathways), we had to conclude that the participating stakeholders tend not to be experts on, or even familiar with, scenario analysis, and hence lacked the necessary knowledge and skills to downscale the global SSPs to scenarios reflecting relevant local and regional dynamics. Furthermore, the restrictions due to the pandemic limited active interactions with the stakeholders. The scenarios presented and discussed in this report were therefore mainly developed and analyzed through desk research in the period between April and October 2021 based on projected regional changes in relevant RCPs and SSPs.

THE SCENARIOS IN RELATION TO THE NORRSTRÖM-BALTIC MODEL

As the scenarios for the Norrström-Baltic area deal with uncertainties *external* to the modelled system, they cannot be understood correctly without knowing the exact delineation of this system. What is 'in'? And what is 'out'? What is part of the modelled system? And what is not? This section therefore gives a brief introduction to the system dynamics model developed within COASTAL. Next, an overview is given of the uncertainties in the system's environment that were taken as a starting point to develop the scenarios.

WHAT DID WE MODEL?

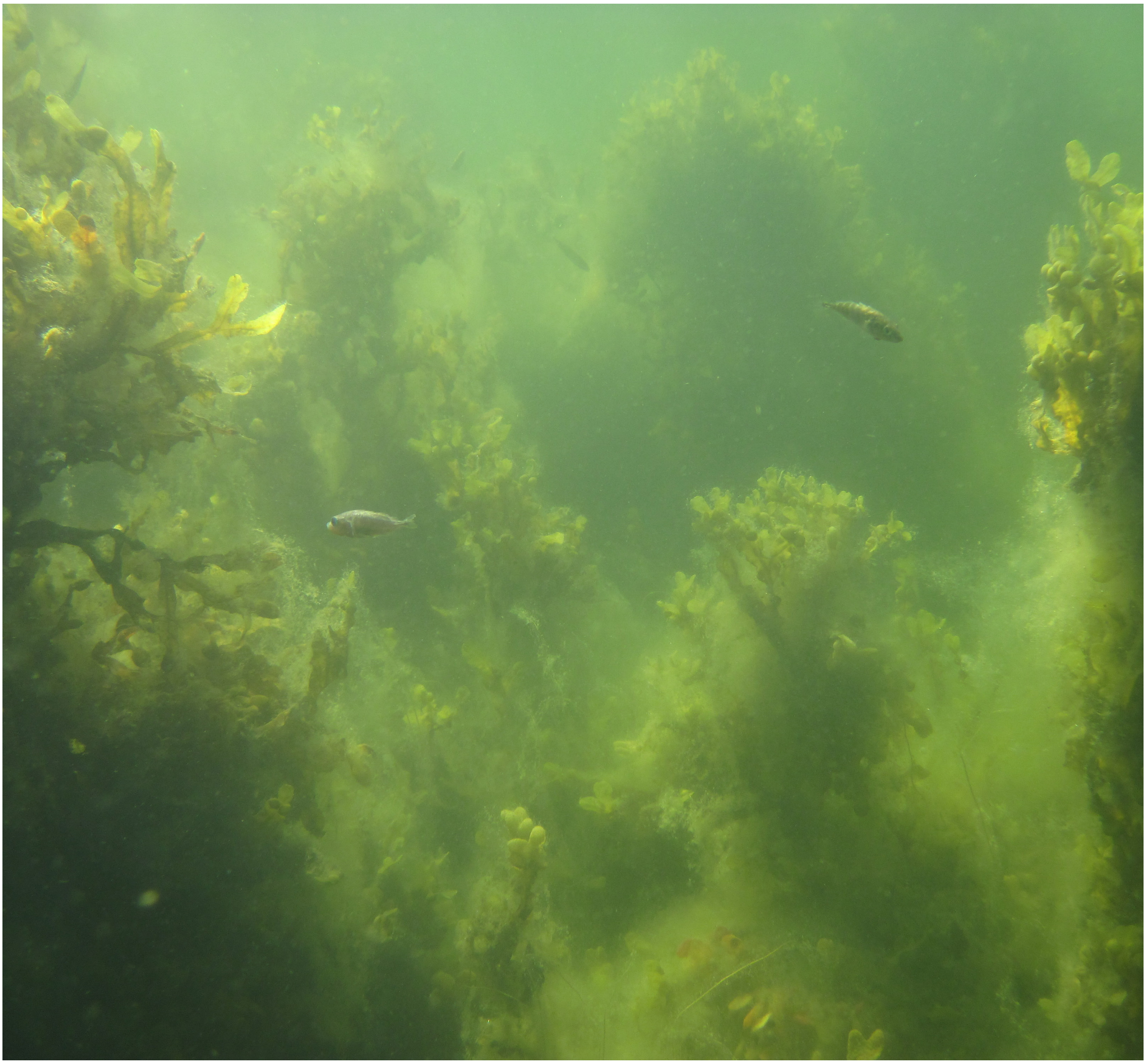
In the Norrström drainage basin and its adjacent and surrounding Baltic coastal zones water availability and quality are affected by population growth and urbanization (Baresel and Destouni, 2005), inland and coastal sectoral activities (e.g. tourism, agriculture, industry), the land-coast-sea water continuum and interactions (Vigouroux et al., 2021), and seawater intrusion into fresh coastal groundwater (Mazi et al., 2016). Associated interactions and impacts are further exacerbated by regional hydro-climatic changes (Bring et al., 2015; Vigouroux et al., 2020). In addition, nutrient legacy sources, accumulated in soil, sediments and slow-moving groundwater from inputs of past human activities, are found to yield dominant load contributions to inland and coastal waters (Chen et al., 2021; Destouni et al., 2021). As such, inland, coastal and marine water quality and ecosystem status in this coastal region still remain in less than good condition in comparison with applicable regulatory targets for water quality, e.g., according to the Baltic Sea Action Plan (Destouni et al., 2017; Vigouroux et al., 2020; HELCOM, 2021).

The Norrström-Baltic model aims to analyze the key land-sea interactions in relation to the above-mentioned water availability and quality challenges and their potential shifts under projected climate change and socio-economic developments in this region. Such interactions and dynamic feedback structures were identified by relevant stakeholders during a series of sector and multi-actor workshops, and were used for SD model development and quantification, that consists of two sub-models as explained below:

- **Land-sea inter-sectoral and coastal water exchange**: This sub-model investigates inland sectoral and coastal system interactions with regard to water fluxes between natural surface and subsurface water systems and the risks related to varying degrees of water availability. It also focuses on the implications of the seaward flow of fresh groundwater that determines seawater intrusion risks, and therefore also allows to shed more light on potentially increasing risks in the future. The model structure includes hydro-climatic catchment conditions, urban, industry, agriculture and forestry sectors, natural surface and subsurface waters, water utilities, urban storm water, and urban and coastal wastewater systems. Urban and coastal tourism are also addressed through various interactions with relevant system components in this part of the model.

- **Land-sea inter-sectoral and coastal waterborne nutrient (nitrogen and phosphorus) exchange:** This sub-model investigates the contributions of various inland and coastal sectors to coastal nutrient (nitrogen and phosphorus) loads through natural surface and subsurface waters, and to potential future changes in these nutrient loads. This sub-model represents hydro-climatic and water flow conditions through links to the water-exchange sub-model (cfr.submodel presented above), and additional interactions of changes in coastal nutrient (nitrogen and phosphorus) loads, associated coastal water quality and ecosystem conditions, and sectoral nitrogen and phosphorus exchanges, and their implications in relation to maximum allowable nitrogen and phosphorus inputs to coastal areas. Such interactions and feedbacks are linked to policy responses that aim for a good water quality status in coastal and marine waters in the Baltic Sea region. Relevant scenarios can be assessed based on the relationships between the water-exchange sub-model and the nitrogen and phosphorus concentrations included in this nutrient-exchange sub-model.

More detailed information about the integrated SD model structure, its variables and associated quantitative information are reported in the COASTAL Deliverable D14 (Viaene et al. 2021) and Deliverable D07 (Seifollahi-Aghmiuni et al., 2020).



WHAT KIND OF EXTERNAL UNCERTAINTIES WERE TAKEN INTO ACCOUNT?

The Norrström-Baltic SD model analyzes possible future shifts in the annual average conditions of sectoral and natural water system interactions. Such shifts are evaluated based on recent annual averages reflecting the condition of system components. Parameters taken into account are, amongst others, sectoral water availability, water fluxes between sectors and the corresponding nutrient (nitrogen and phosphorus) exchanges, coastal runoff and nitrogen and phosphorous loads ending up in the Baltic Sea. As explained in the introductory part of this report, the Shared Socio-economic Pathways (SSPs) and the Representative Concentration Pathways (RCPs), were used as a common starting point to develop the model-specific scenarios. The table below provides an overview of the parameters from this generic framework identified as being system external uncertainties that may affect the behaviour of the model. The second column displays the input variables where the scenarios connect with the modelled system. The third column lists the parameters from the generic scenario framework that were considered to explain the future evolution of these model-specific input variables.

N°	Model input variable	System-external uncertainties affecting this model input variable
1	Precipitation	Climate change
2	Agricultural land	Development policies and market forces, food security and trade regulations, population growth and corresponding food demand/diet changes
3	Built-up land	Development policies and market forces, population growth, regional urbanization level, tourism expansion level
4	Forest land	Mitigation policies on climate change (i.e. afforestation and/or reforestation to maintain/enhance carbon capture and storage capacity), socio-economic developments leading to sectoral land competition (i.e. deforestation)
5	Open lands and wetlands	Policies and market forces supporting social and economic development in the region

DETAILED DESCRIPTION OF THE SCENARIOS

In total, we developed 5 scenarios for the Norrström/Baltic Sea case. One of them represents the 'Base case' conditions, while the rest are rooted in the combination of a certain SSP with a climate scenario linked to a certain RCP. The following overview shows the combinations used during the scenario building process:

- **Scenario 1**: SSP1 + RCP 4.5
- **Scenario 2**: SSP2 + RCP 4.5
- **Scenario 3**: SSP4 + RCP 4.5
- **Scenario 4**: SSP5 + RCP 4.5
- **Base Case scenario**: Continuation into the future of the past-recent long-term average conditions in relation to hydro-climate and land use variables in the SD model.

As can be seen in this overview, all the scenarios developed for the Norrström-Baltic region are linked to a climate scenario corresponding with RCP4.5. This is because projected patterns and changes for climate variables under this climate scenario were found to be more consistent with the observed changes in the region than other RCPs.

In the remaining part of this section, the future evolution of each of the model input variables listed in the table above is described qualitatively under each of the defined scenarios. The corresponding quantitative data can be found via this link to the online data repository. The quantitative descriptions are included in COASTAL's data repository and can be accessed by clicking on the links inserted in this document. To develop these region-specific scenario descriptions the following steps were taken:

- **Step 1** – Based on climate research and modelling conducted by the Swedish Meteorological and Hydrological Institute (SMHI) (https://www.smhi.se/en/climate/future-climate/climate-scenarios/), qualitative and quantitative descriptions were made for projected changes linked to climate related model input variables under a climate scenario corresponding with RCP4.5.
- **Step 2** – For all non-climate input variables, the qualitative descriptions of the projected changes under each of the SSPs were interpreted in the context of the Norrström-Baltic coastal region. This way, we could better understand the change patterns those variables should follow in the SD model. For this, the summary of integrated SSP and IPCC criteria developed by WP5 was used.
- **Step 3** – The change pattern identified for each non-climate input variable was quantified based on the SSP Database developed by International Institute for Applied Systems Analysis (IIASA) (https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10).
- **Step 4** – The downscaled and quantified change patterns were incorporated in the Norrström-Baltic SD model. Next, the outcomes were analysed in relation to different key performance indicators (KPIs). To investigate shifts in long-term annual average conditions, the downscaled changes were applied in the middle of the simulation period (year 2060 during 2010-2110) as instant increases or decreases in relevant variables. The resulting new average conditions developed within the system were then considered for KPI analysis.

1. PRECIPITATION

The long-term annual average precipitation rate in the Norrström-Baltic coastal region is currently estimated at 652 mm/yr (Cseh, 2009). In our analysis this average value is included in the Base Case scenario. However, climate change is expected to lead to an increase in precipitation in this region (see also Figure 1). Therefore long-term annual average precipitation is considered to increase in all the scenarios by about 11%, which is the precipitation increase corresponding with RCP4.5.

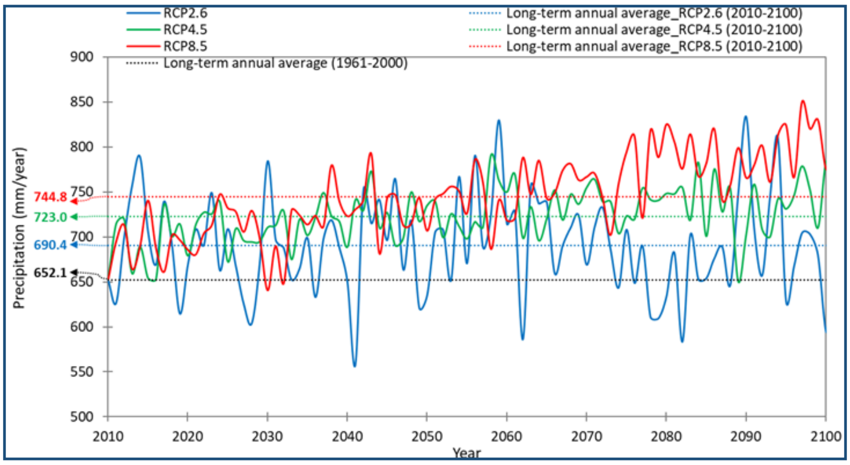


Figure 1*. Annual precipitation changes in the Norrström drainage basin (inland catchment of the Norrström-Baltic coastal region) projected for different representative concentration pathway scenarios (RCPs) during 2010-2100 (SMHI online database). Long-term annual average precipitation for RCP4.5 is equal to 723 mm/yr, indicating around 11% increase compared with the long-term annual average 1961-2000 (652.1 mm/yr - Base Case condition).*

2. AGRICULTURAL LAND

The total area of the Norrström drainage basin is about 22,600 km^2 (Lindgren et al., 2007; Cseh, 2009). The long-term average area of agricultural land in this catchment is estimated at approximately 10% of the total catchment area (Chen et al., 2021), that is 2122.9 km^2, and is included in the Base Case scenario, .

Development policies driving sectoral land competition, trade regulations, market forces on local food production, dietary changes, population growth and changes in lifestyle are external uncertainties in the modelled land-sea system that can influence the future share of agricultural land in this region. Figure 2 shows the expected evolution in agricultural land under each of the SSPs. This evolution follows the projections for the countries that are a member of the Organization for Economic Co-operation and Development (OECD) with the following scenario-specific changes:

SCENARIO 1

This scenario is developed based on SSP1 under which domestic food demand is projected to shift towards plant-based diets and bio-based materials with gradual reduction in food waste and per capita demand for livestock-based products (Mitter et al., 2020). However, the urbanization level is expected to be high with rapid regional development in SSP1 (Riahi et al., 2017). As the result of sectoral land competition, agricultural land area is expected to decrease by 13% in this scenario (cfr. IIASA online database).

SCENARIO 2

This scenario is developed based on SSP2 under which European agricultural policy is expected to support increasing productivity and efficiency. The demand for locally produced food is expected to increase slowly, whereas per capita meat demand is expected to remain high (Mitter et al., 2020). Therefore, a continues and gradual growth of the agriculture and food economy is considered in this scenario, corresponding with an increase rate of 9% for agricultural land (cfr. IIASA online database).

SCENARIO 3

This scenario is developed based on SSP4 under which European agricultural policies are expected to increasingly support economic growth and technology development, which will benefit the large and industrialized farms the most (Mitter et al., 2020). Therefore, the long-term average share of agricultural land is considered to increase by 16% in this scenario (cfr. IIASA online database).

SCENARIO 4

This scenario is developed based on SSP5 under which European imports of agricultural commodities are expected to increase, private investments in technological know-how and the education of employees in the agriculture and food systems are expected to boost economic growth, while public payments to the agriculture and food systems are expected to be reduced to conform with liberalized and integrated European markets (Mitter et al., 2020). Consequently, the long-term average share of agricultural land in this scenario is expected to slightly decrease with a rate of 1.5% (cfr. IIASA online database).

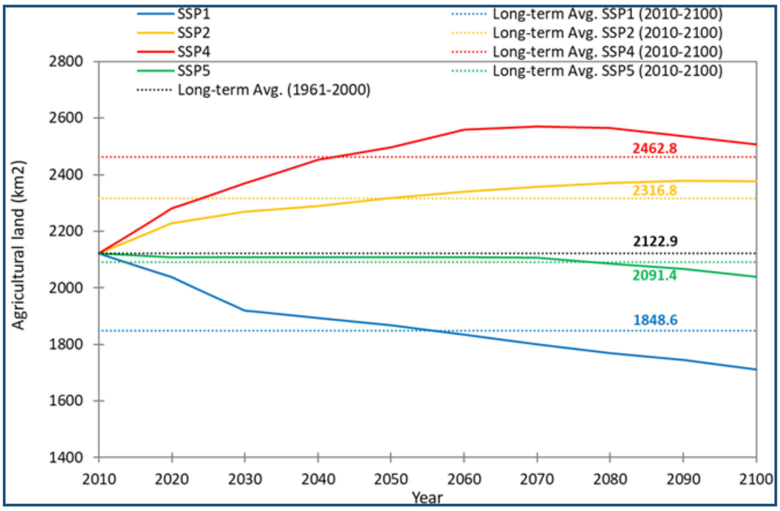


***Figure 2**. Annual average change in agricultural land in the Norrström-Baltic region according to the projections for OECD coutries under different shared socio-economic pathways (SSPs) during 2010-2100 (IIASA online database).*

3. BUILT-UP LAND

The long-term average area of built-up (urbanized) land in the Norrström-Baltic region is estimated at approximately 4% of the total area of the Norrström drainage basin (Cseh., 2009). This value is therefore included in the Base Case scenario, namely 857.3 km^2. Development policies driving sectoral land competition, population growth and increasing demand for accommodation, market forces driving regional economic growth, and inland and coastal tourism expansion are external uncertainties to the land-sea system in the region that can influence the share of built-up land. Figure 3 shows the expected evolution of built-up land areas in the region for different SSPs with the following scenario-specific changes:

SCENARIO 1

This scenario is developed based on SSP1 under which European population size is expected to be stable while the percentage of people living in urban areas and the urbanization level are expected to increase (Riahi et al., 2017; Mitter et al., 2020). Therefore, built-up land area is considered to increase by 55% in this scenario (cfr. IIASA online database).

SCENARIOS 2, 3 & 4

These scenarios are developed based on SSP2, SSP4 and SSP5, respectively. European population size and the urbanization level are expected to be stable under SSP2 and SSP4 (Mitter et al., 2020). Therefore, built-up land area in the region is considered to be stable for Scenarios 2 and 3, and hence on the same level of the Base Case scenario. There was no data available for the evoluation of built-up land under SSP2 for OECD regions in the IIASA online database. As a result, the corresponding changes are not shown in Figure 3. Under SSP5, European population size, the percentage of people living in urban areas and the urbanization level are expected to increase throughout Europe (Mitter et al., 2020). However, the built-up land area is expected to be stable in the OECD region (IIASA online database). As such, the same level of built-up land area in the Base Case scenario is also considered for Scenario 4.

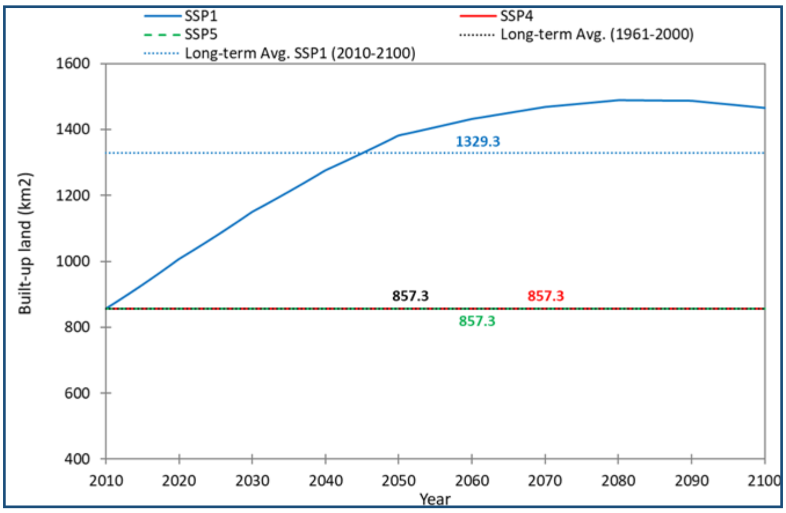


Figure 3*. Annual average change in built-up land in the Norrström-Baltic region according to the projections for OECD countries under different shared socio-economic pathways (SSPs) during 2010-2100 (IIASA online database).*

4. FOREST LAND

The long-term average area of forest land in the Norrström-Baltic region is estimated at approximately 49% of the total area of the Norrström drainage basin (Cseh., 2009). This value is therefore included in the Base Case scenario, namely 11258.2 km^2. Development policies driving sectoral land competition and mitigation policies on climate change to maintain and/or increase carbon sequestration capacity, are external uncertainties to the land-sea system that may influence forest land share in this region. However, Sweden has set a climate goal, as part of its Climate Act framework (The Swedish Government, 2017), to have zero net emissions of greenhouse gases into the atmosphere by 2045. This is followed by increasing carbon sequestration in forest lands, as important natural resources to support mitigation plans. As a consequence, significant changes in forest areas are not expected in the region. Figure 4 shows the expected annual evolution of forest land in the region for different SSPs with the following scenario-specific changes:

SCENARIOS 1 & 2

These scenarios are developed based on SSP1 and SSP2, respectively. Natural resource depletion is expected to decrease under SSP1 and increase under SSP2 (Mitter et al., 2020). The expansion of forest land cover (afforestation and/or reforestation) is considered as an important option for climate change mitigation in SSP1 and followed by SSP2 (Riahi et al., 2017). Therefore, the long-term average share of forest land is considered to increase by 9% and 2% in the region for Scenarios 1 and 2, respectively (cfr. IIASA online database).

SCENARIOS 3 & 4

These scenarios are developed based on SSP4 and SSP5, respectively. Natural resource depletion is expected to increase under SSP4 and SSP5 (Mitter et al., 2020). Therefore, the share of forest land is considered to slightly decrease by 0.5% and 0.3% in the region under Scenarios 3 and 4, respectively (cfr. IIASA online database).

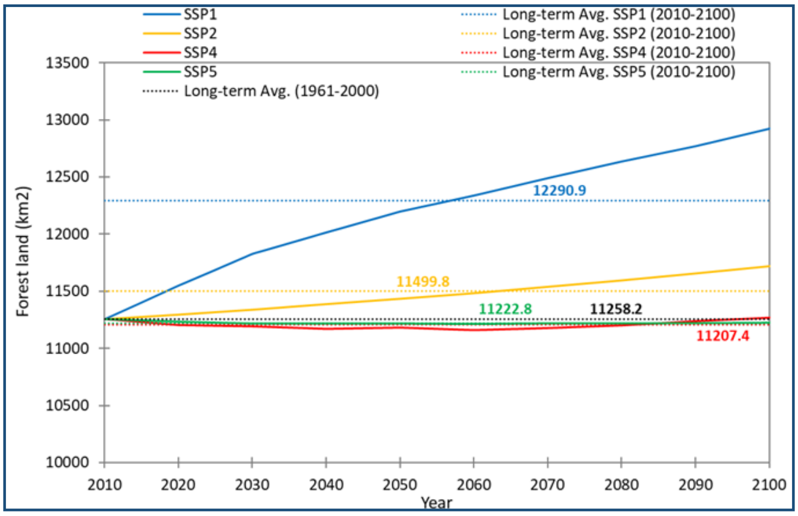


***Figure 4**. Annual average change in forest land in the Norrström-Baltic region according to the projections for OECD countries under different shared socio-economic pathways (SSPs) during 2010-2100 (IIASA online database).*

5. OPEN LANDS AND WETLANDS

The long-term average area of open lands and wetlands in the Norrström-Baltic region is estimated at 27.5% of the total area of the Norrström drainage basin (Cseh., 2009). This value is therefore included in the Base Case scenario, namely 6215.0 km^2. Policies and market forces supporting regional socio-economic development are external uncertainties that may influence the share of open land and wetlands in this region. To meet the constraint of the total area of the catchment, which will not change, all the scenario-specific changes explained above for agricultural, built-up and forest land are applied in exchange with open land and wetland areas in the SD model. This means that any increase or decrease in those land covers will result in a corresponding decrease or increase of the share of open land and wetland areas in the model. As a result, the share of open land and wetland areas is considered to decrease by 20% and 4.6% in Scenarios 1 and 3, respectively, and to increase by 6.8% and 1% in Scenarios 2 and 4, respectively.

COMPARISON OF THE DYNAMIC PATTERNS OF KEY PERFORMANCE INDICATORS

To evaluate the impact of the scenarios on the modelled system for the Norrström-Baltic region, and thus to investigate the change patterns of the model's key variables, the SD model was run over a 100-year simulation period (2010-2110). In order to do this, the model's input variables had to be changed for each of the scenarios, as explained in the previous section.

To select appropriate key performance indicators (KPIs), we went back to the final simulation step of the SD model (as outlined in Viaene et al. (2021)) and assessed the outcomes at the level of different output variables. Based on this evaluation, we decided which model output variables could be considered useful KPIs of the two sub-models for the land-sea system. These KPIs represent various relevant water quantity and quality characteristics in relation to different socio-economic sectors (anthropogenic impacts), natural water sub-systems (anthropogenic and climate-change impacts propagated through natural/physical water-system functions), and policy and management aspects (regional policy/management change/development impacts). See Figure 5 below for a more schematic overview.

For the **water quantity sub-model**, all output variables outlined in Viaene et al. (2021) have relevant implications for water availability (total water flows and flow exchanges) in each sector/sub-system, net water flows through the natural inland water sub-systems and into the coastal-marine waters, and associated seawater-intrusion (salinity, i.e., quality) conditions for coastal freshwater, which make them all useful as KPIs. For the **water quality sub-model**, the assessment showed that only a subset of all model outputs are useful as KPIs, specifically those of net input and net load of total nitrogen (TN) or total phosphorus (TP) for each socio-economic sector and natural water sub-system, as these net inputs and loads clarify if, and to what degree, a sector constitutes a source or sink of anthropogenic TN and/or TP. They also clarify the amounts of TN and TP following inland waterways and finally ending up in coastal and marine waters.

Model outputs of gross total flows of TN and TP through a sector or sub-system, on the other hand, are not useful as KPIs for COASTAL's study purposes. This is because they include and add up multiple inter-sectoral/sub-system exchanges of the same TN and TP amounts, which in turn also include dominant natural/background (i.e., not anthropogenic) TN and TP contents that are present in all water flows and water exchanges among sectors and sub-systems. The gross total flow exchanges are therefore not helpful in clarifying the net anthropogenic nutrient load contributions and source/sink functions of different sectors and natural water sub-systems.

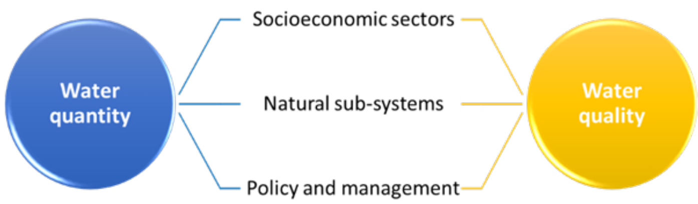


Figure 5. *System aspects addressed and quantified by the key performance indicators (KPIs) from the MAL3 system dynamics (SD) model.*

In the remaining part of this chapter, the SD model scenario results are discussed and illustrated (in Figures 6-11) for the considered sets of useful KPIs, which are also listed in the table below.

	Water Quantity			Water Quality		
Subsystem	Water flows/availability for...			Net inputs and loads of total nitrogen (TN) and total phosphorus (TP) for...		
Socio-economic sectors	Green sectors (Agriculture, Forestry and natural ecosystems, Open lands and wetlands)	Urban and tourism sectors (Municipal water supply, Industry, Urban surface runoff)	Wastewater systems (Municipal wastewater treatment plants; Unconnected coastal wastewater)	Agriculture	Industry; Urban surface runoff	Wastewater systems (Municipal wastewater treatment plants; unconnected coastal wastewater)
Natural subsystems	Surface and subsurface water systems	Green water flow (evapo-transpiration)	Blue water flow (Coastal outflows by surface and subsurface water runoffs)	Surface water system	Subsurface water system	Coastal-marine system
Policy and management	Proxy of coastal seawater intrusion risk			Baltic Sea Action Plan (BSAP) policy-function indicators for TN and TP		

1. KPI RESULTS COVERING WATER AVAILABILITY FOR SOCIO-ECONOMIC SECTORS

Annual average sectoral water availability, or the gross total water flow through a sector, which includes all water flows and flow exchanges, depends on natural renewable water availability in the Norrström-Baltic land-sea system, as well as land cover changes in this system. The value of relevant KPIs for each scenario is shown and compared with the Base Case Scenario in Figure 6. This overview indicates the following:

- Water availability will increase for the green sectors under Scenarios 2, 3 & 4 (the yellow, green and orange columns) compared to the Base Case Scenario (the grey column). The amount of water available for agriculture and open lands and wetlands will decrease under Scenario 1 (the white column), since the area of these lands is expected to decrease under this scenario, which will result in less precipitation water on these lands despite the regionally projected increase in precipitation.
- The changes in water availability for the green sectors between the different scenarios are not significant, and resulted from land cover changes.
- For other socio-economic sectors than the green sectors, water availability under the Scenarios 2, 3 & 4 (the yellow, green and orange columns) will stay at the same level as the Base Case Scenario (the grey column), except for urban surface runoff and wastewater treatment plants, which will experience higher water flows due to the projected precipitation increase. Intensive urbanization, together with the precipitation increase expected under Scenario 1 (the white columns), implies higher water flows through municipal water utilities with higher volumes of urban surface runoff (as urban storm water) and higher volumes of municipal wastewater, which both need to be handled in this region.

In general, Scenario 1 implies higher water availability for almost all socio-economic sectors. Further management measures will be needed for storm and wastewater handling in the urban areas.

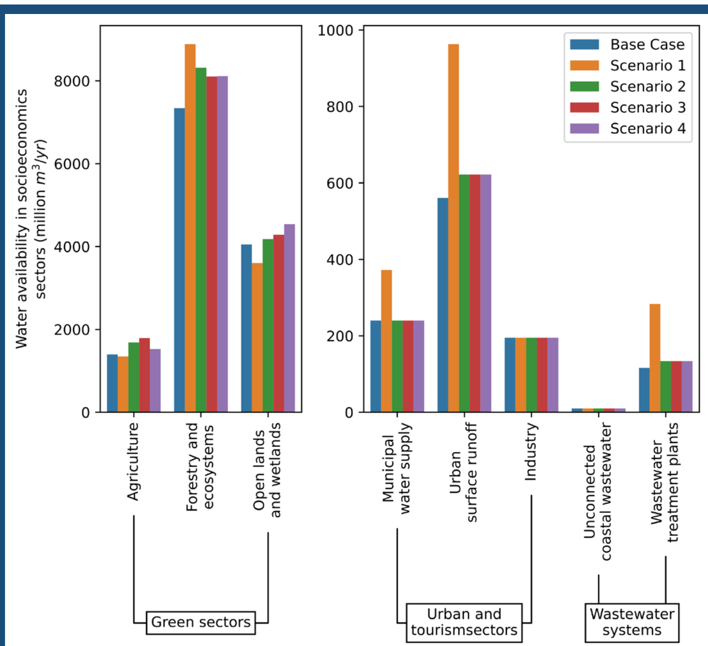
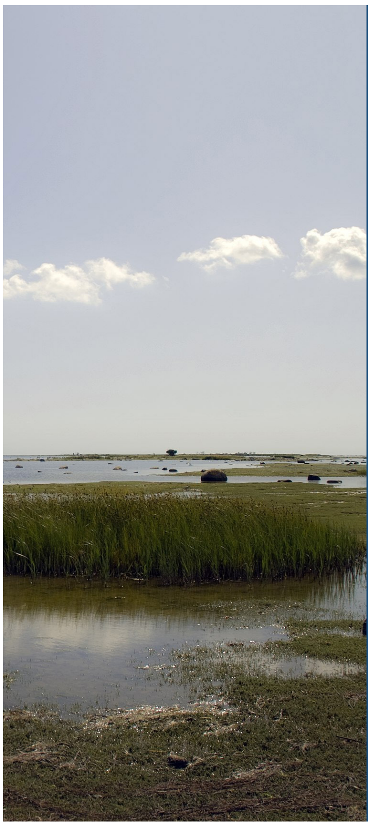


Figure 6*. Scenario results of key performance indicators (KPIs) for water quantity in different socio-economic sectors in the Norrström-Baltic region in 2060. Water availability refers to the total water flows and flow exchanges for each sector. The left vertical axis shows the KPI values for green sectors and the right vertical axis shows the KPI values for urban and tourism sectors and wastewater systems.*

2. KPI RESULTS COVERING WATER AVAILABILITY FOR NATURAL SUB-SYSTEMS

Annual average water availability and net flows through natural water sub-systems, which include the surface and subsurface water systems and the coastal-marine water that receive net freshwater flows (discharges) from the former, depend on the renewable water availability in the system and the water flow exchanges between natural sub-systems and interacting socio-economic sectors. The values of relevant KPIs for each scenario are shown and compared with the Base Case scenario in Figure 7, with results indicating that:

- Water flows through natural sub-systems will increase for Scenarios 1 until 4 compared with the Base Case scenario (the grey column), as a result of the regional precipitation increase. However, green water flow (regional evapotranspiration) will only increase for Scenario 1 (the white column) due to the evaporation increase from built-up areas (urban surface runoff) and the evapotranspiration increase from forest lands, resulting from their expansion in this scenario for the region.
- Water flows through natural sub-systems differ slightly between Scenarios 1 until 4 due to land cover changes.
- The blue water flow (coastal outflow) will increase for Scenarios 1 until 4 as a result of increase in surface and subsurface runoffs to the coast due to precipitation increase and land cover changes. The contribution of surface runoff to coastal outflow is almost twice as much as the contribution of subsurface runoff to coastal outflow for all scenarios. Overall, these results highlight the future need to handle increased coastal runoff through both pathways to the coast.



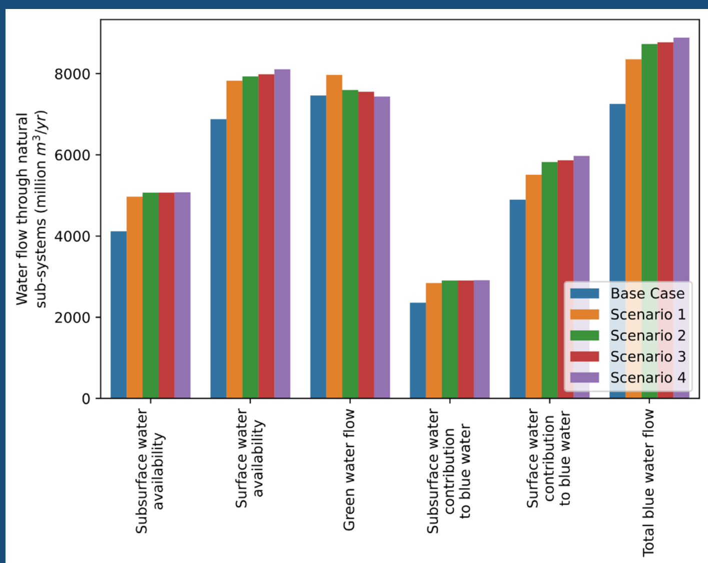


Figure 7*. Scenario results of key performance indicators (KPIs) for water quantity in different socio-economic sectors in the Norrström-Baltic region in 2060. Water availability refers to the total water flows and flow exchanges for each sector. The left vertical axis shows the KPI values for green sectors and the right vertical axis shows the KPI values for urban and tourism*

3. KPI RESULTS LINKED TO WATER QUANTITY MANAGEMENT IMPACTING WATER QUALITY (SALINITY)

This management KPI addresses the risk of seawater intrusion for fresh coastal groundwater in the Norrström-Baltic area. The structure of this KPI is explained in the COASTAL Deliverable D07 (Seifollahi-Aghmiuni et al., 2020). Zero value for this KPI indicates no change from current seawater intrusion risk while positive (negative) values indicate higher (lower) risks compared to the Base Case Scenario. Figure 8 shows that, for all scenarios (blue dots), the seawater intrusion risk in the coastal region is lower than in the Base Case Scenario (black line), indicating less impact on fresh coastal groundwater resources from intruding seawater. This is due to the higher land-based coastal outflow of groundwater (subsurface contribution to total blue water in Figure 7) that pushes the intrusion interface further towards the sea, thereby improving the quality (in terms of salinity) of coastal groundwater. This phenomenon can also decrease the recirculation of seawater after intrusion into coastal aquifers and the associated re-mobilisation and loading of nutrients and/or other pollutants to coastal waters.

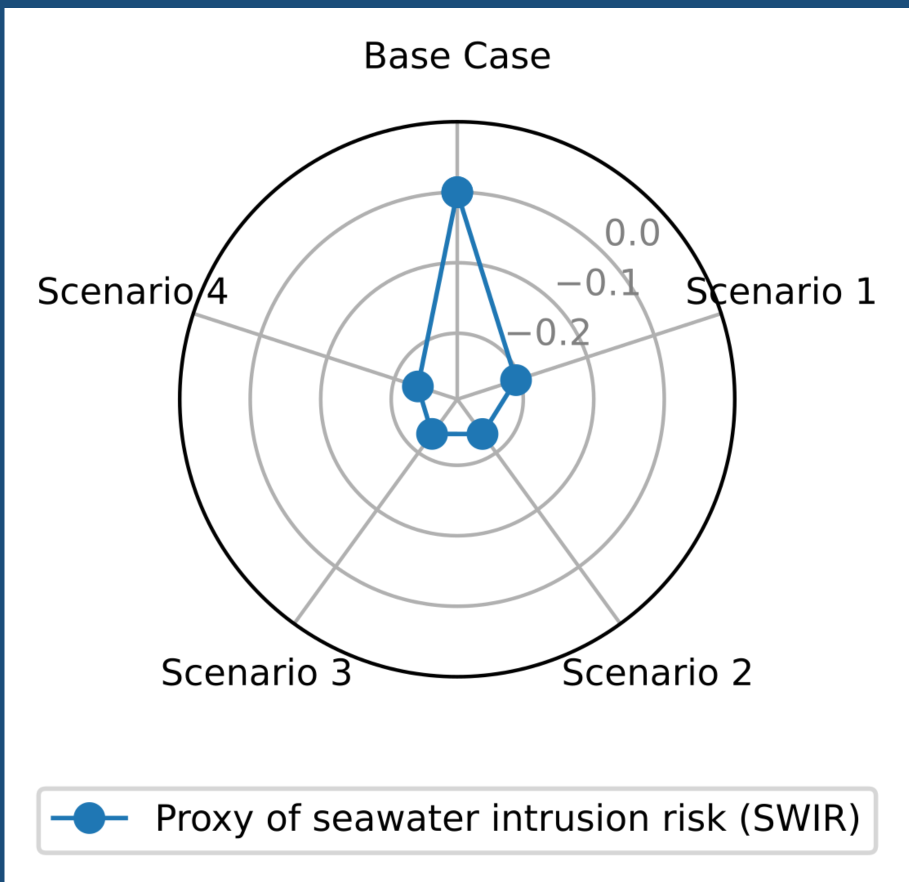
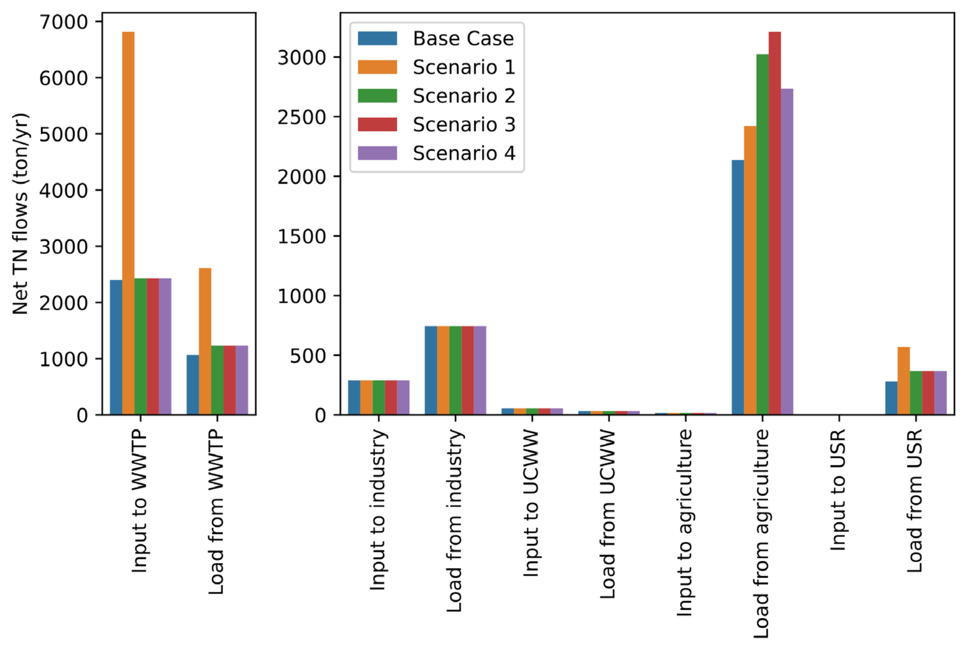


Figure 8. *Scenario results for the management key performance indicator (KPI, dimensionless) of seawater intrusion risk in 2060. Higher KPI value implies higher seawater intrusion risk.*

4. KPI RESULTS ON NET WATERBORNE TN AND TP INPUTS TO AND LOADS FROM SOCIO-ECONOMIC SECTORS

Based on an assessment of the sectoral interactions in the Norrström-Baltic land-sea system (Viaene et al., 2020 and 2021; Seifollahi-Aghmiuni et al., 2021), 20 useful KPIs were considered with regard to waterborne TN and TP inputs to, and loads from, various socio-economic sectors. On average, waterborne TN and TP loads in the Norrström-Baltic water system depend on the annual average nutrient-carrying water flows and the average TN and TP concentration levels in these flows. Based on an analysis of long-term data series, the latter are considered to remain more or less at the same level in the Norrström-Baltic scenarios as in the Base Case Scenario, while the water flows change depending on the scenarios (see KPI results for water quantity above and in Figures 6-7). The KPI results for water quality under different scenarios are shown in Figure 9, indicating that:

- Scenario differences for net TN (top graph) and TP (bottom graph) flows through the agricultural sector follow, as expected, the same pattern as the agricultural water availability differences (Figure 6), since more or less similar nutrient concentrations are transported by shifting water flows.
- The agricultural sector has much greater TP and TN output than input loads - considerably higher than the other socio-economic sectors - and thus functions clearly as a major source and contributor to the water quality problems in the inland and coastal systems.
- Also industry has higher TN and TP output than input loads. As a consequence, industry is also identified as a sector with considerable source contributions to the water quality problems in the inland and coastal waters (third and second for TN and TP, respectively).
- Urban surface runoff (USR) is a net source contributor of TN loads to the coastal system under all scenarios, but on a very low level compared to other socio-economic sectors, as are also the USR-related average net TP loads over the whole catchment area. Although these net flows may be locally large in urban areas. In analogy, the net TN and TP inputs to and loads from localized unconnected coastal wastewater (UCWW) are overall very low under all scenarios, that is in the order of less than 50 and 1 ton/year for TN and TP, respectively.
- Wastewater treatment plants (WWTP) represent the only socio-economic sector in the modelled system that is designed and meant to remove nutrients from the net inputs to this sector, and hence acts as a major nutrient sink with large net mitigation of both TN and TP loads (see Figure 9). Nevertheless, this sector still contributes considerable TN and TP loads, as a result of which it is, respectively, the second and third largest emitter of TN and TP in the Norrström-Baltic region.
- Besides the agricultural sector, the results of WWTPs also show some considerable differences between the scenarios. For Scenarios 2 until 4 (the yellow, green and orange columns), TN and TP flows through WWTPs are the same as the Base Case Scenario (the grey column), because those scenarios do not involve any change in built-up land cover, nor in the associated urban and tourism sectors. Scenario 1 (the white column), however, represents a high urbanization level with corresponding high TN and TP inputs to and loads from WWTPs. This highlights the great need for higher investments in enhanced wastewater treatment systems to efficiently mitigate the expected higher TN and TP loads under scenarios characterized by high urbanisation levels (Scenario 1).



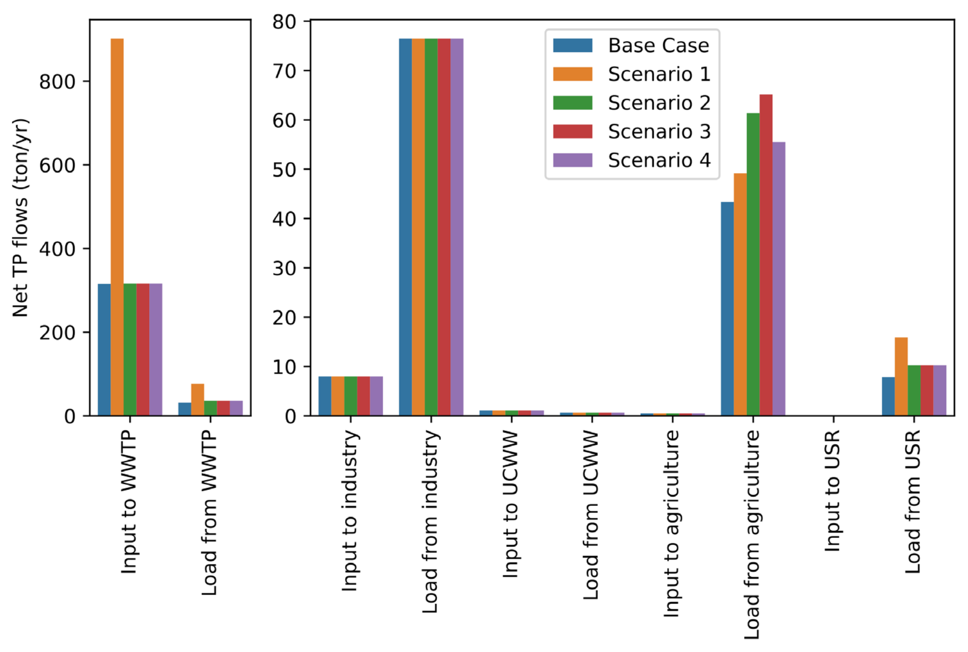
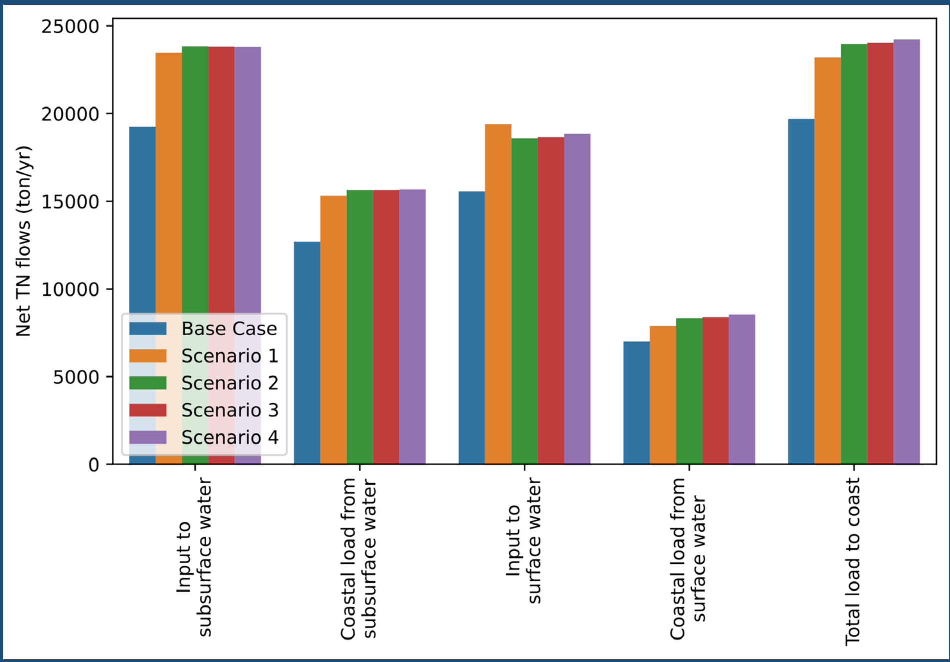


Figure 9. *Scenario results of key performance indicators (KPIs) for water quality in 2060 from the Norrström-Baltic system dynamics (SD) model. The KPI results shown here for different socio-economic sectors present the net total nitrogen (TN; top graph) and net total phosphorus (TP; bottom graph) inputs to and loads from each sector. The sectors include wastewater treatment plants (WWTPs), industry, unconnected coastal wastewater (UCWW), agriculture and urban surface runoff (USR). The left vertical axis shows the KPI values for WWTPs and the right vertical axis shows the KPI values for other sectors.*



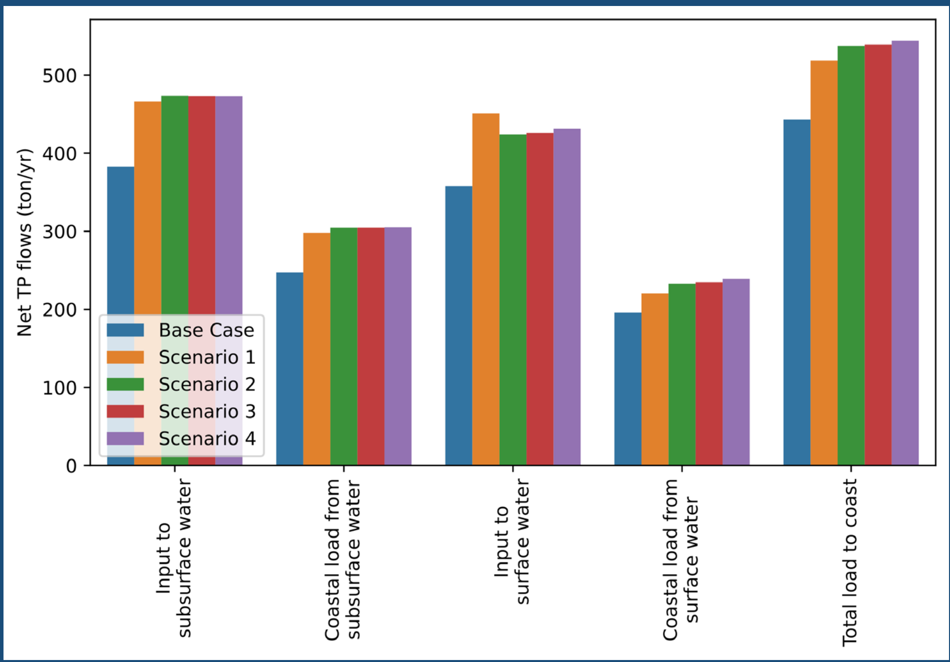


Figure 10. *Scenario results of key performance indicators (KPIs) for water quality in 2060 from the Norrström-Baltic system dynamics (SD) model. These KPI results show the net total nitrogen (TN; top graph) and net total phosphorous (TP) inputs to and loads for different natural water sub-systems. The latter include surface waters, subsurface waters and the coastal-marine water system.*

5. KPI RESULTS ON NET WATERBORNE TN AND TP INPUTS TO AND LOADS FROM NATURAL SUB-SYSTEMS

For the net TN and TP inputs to and loads from natural water subsystems, including surface and subsurface waters, and hence also the TN and TP loads finally ending up in the coastal-marine waters, we considered 10 KPIs. The results are shown in Figure 10 and indicate that:

- Under all scenarios, the net TN and TP inputs from the socio-economic sectors to subsurface waters are higher than those to surface waters. This difference propagates further to higher coastal loads of TN and TP through subsurface water (groundwater) than from surface water (streams, rivers) (cfr. Figure 10), even though the subsurface water flow is considerably lower than the surface water flow to the coast in the Norrström-Baltic water system (cfr. Figure 7). These results are due to higher TN and TP concentrations in subsurface waters than in surface waters, which is in turn likely due to dominant continuous nitrogen and phosphorus releases from subsurface legacy sources to more mobile, flowing groundwater and further into downgradient coastal waters (Chen et al., 2021; Destouni et al., 2021).
- The net TN and TP inputs to each natural water subsystem are higher than the corresponding net loads flowing to the coastal waters from both the subsurface and the surface waters. This shows a degree of ongoing TN and TP retention (and for TN also some irreversible denitrification) in both these subsystems, which lowers current TN and TP loads released in coastal waters, but at the same time adds to building-up and maintaining the legacy sources that remain in the soil, slow-flowing groundwater and surface-water sediments. The TN and TP loads generated today will be part of the legacy sources of tomorrow. Also in the future these legacy sources will continue to release nutrients into the coastal waters complementary to the future nutrient loads emitted by the various socio-economic sectors active in the region.
- Overall, the net TN and TP loads to the coast are higher in all scenarios than in the Base Case scenario, highlighting a general need for further nutrient load mitigation measures in the future.

6. KPI RESULTS ON POLICY AND MANAGEMENT INDICATORS FOR WATER QUALITY

Finally, two policy-related KPIs are considered that are directly related to coastal nitrogen and phosphorus load mitigation targets set as part of the Baltic Sea Action Plan (BSAP) (HELCOM 2021) for the marine basin of Northern Baltic Proper. Zero values for these KPIs indicate that the BSAP target loads are achieved, while positive values indicate higher nutrient loads than the targets – i.e., worse water quality conditions than required in the BSAP. Figure 11 shows that, despite various mitigation measures taken over the past decades, both nitrogen (Figure 11a) and phosphorus loads (Figure 11b) at Norrström-Baltic coast are still above the BSAP target loads (the black square) in the Base Case scenario (representing the recent-current condition – the dashed black line). The increase in the values under the Scenarios 1 until 4 (blue dots) indicate even higher nitrogen and phosphorus loads to the coast under these scenarios. This implies that the water quality in the coastal and marine waters is expected to get even worse than today under all scenarios. This highlights the necessity for effective mitigation policies and measures that take into account (i) the whole spectrum of nutrient load impacts from various current (active)/historical (legacy) types of diffuse and point polluting sources, and (ii) the overall cross-boundary condition of this coastal region. The latter implies that the coastal and marine water quality problems in this region are not only derived from local nutrient loads of the Norrström drainage basin case, but also from pollution occurring at the macro-regional/ transboundary scale of the whole semi-enclosed Baltic Sea and the associated catchment areas. The open sea conditions also greatly influence the local coastal conditions, in addition to the influences from the local coastal catchment. As such, multi-scale and multi-sectoral mitigation policies and measures are required to address the water quality problems in the Norrström-Baltic coastal and marine environment.

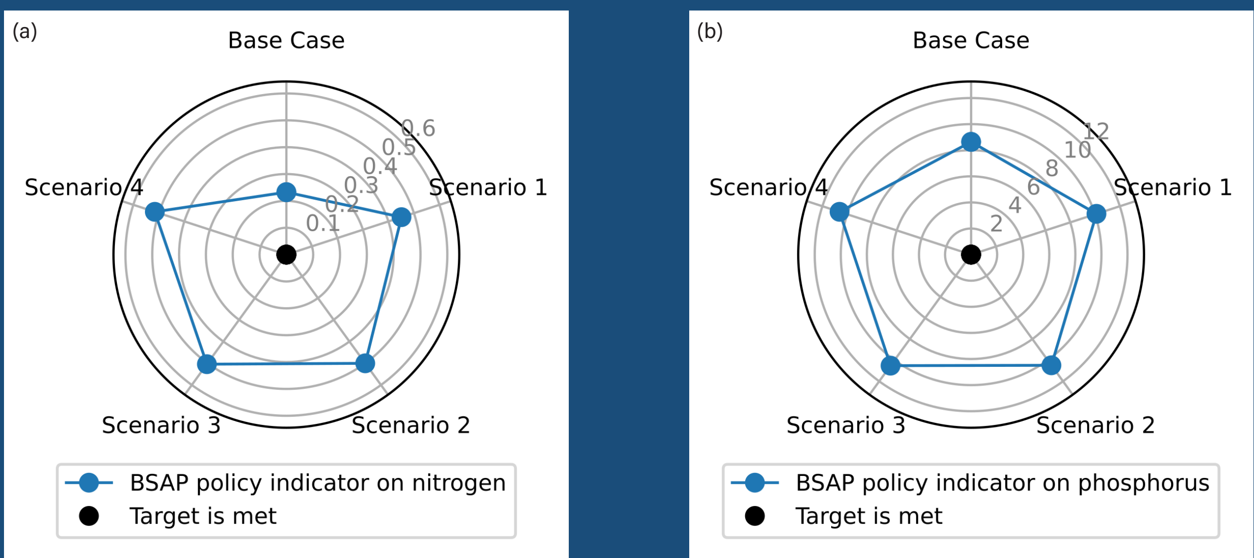


Figure 11. *Policy-related key performance indicators (dimensionless) showing the achievement (KPI values of zero) or non-achievement (KPI values > 0) of the Baltic Sea Action Plan (BSAP) mitigation targets for: (a) coastal nitrogen load; and (b) coastal phosphorus load. The KPI results are shown for the different scenarios.*

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CYANOBACTERIAL BLOOMS IN THE BALTIC SEA
MODIS AQUA 2005-07-11, data from NASA
processed by SMHI

SCENARIOS FOR THE OUDLANDPOLDER

D'Haese, N., De Kok, J.-L., Viaene, P. and Notebaert, B.

COASTAL
Collaborative Land-Sea Integration Platform

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CONTEXTUAL ELEMENTS INFLUENCING SCENARIO BUILDING

The **Oudlandpolder** contains about 17.000 ha of land reclaimed from the sea. The landscape emerged from centuries of battles against high tides, ultimately won by farmers who developed sophisticated systems of dikes and (little) channels to safeguard their pastures from the salty water. From the 10^{th} century on until today, water management practices have therefore had a pivotal role in the development of this region.

As a result of changing climate patterns and an intensification of agricultural and other water consuming practices, the Oudlandpolder suffered from severe droughts during the last hot summers. The delicate balance between fresh water supply and demand, which had been built up during centuries, appears to be difficult to maintain under the current challenging circumstances. As a result, the polder threatens to become more and more saline, flooding risks increase, and some essential sectors, such as agriculture and nature, are confronted with severe water shortages. **A thorough reorganization of the water system in the area is** therefore **unavoidable**.

As a result, a **framework agreement was signed in 2018 by all governmental bodies responsible for water management in the Oudlandpolder**, that is the Flemish minister of environment, nature and agriculture, the Province of West-Flanders, all municipalities having (part of) their territory in the Oudlandpolder, the Flemish environmental department, the Flemish agricultural department, the Flemish maritime department, the Flemish agency for nature and forests, the Flanders heritage agency, the Flemish environmental agency, the Flemish land agency, the polder's dike warden, and representatives of nature and agricultural organizations.
The objectives of this framework agreement can be summarized as follows:

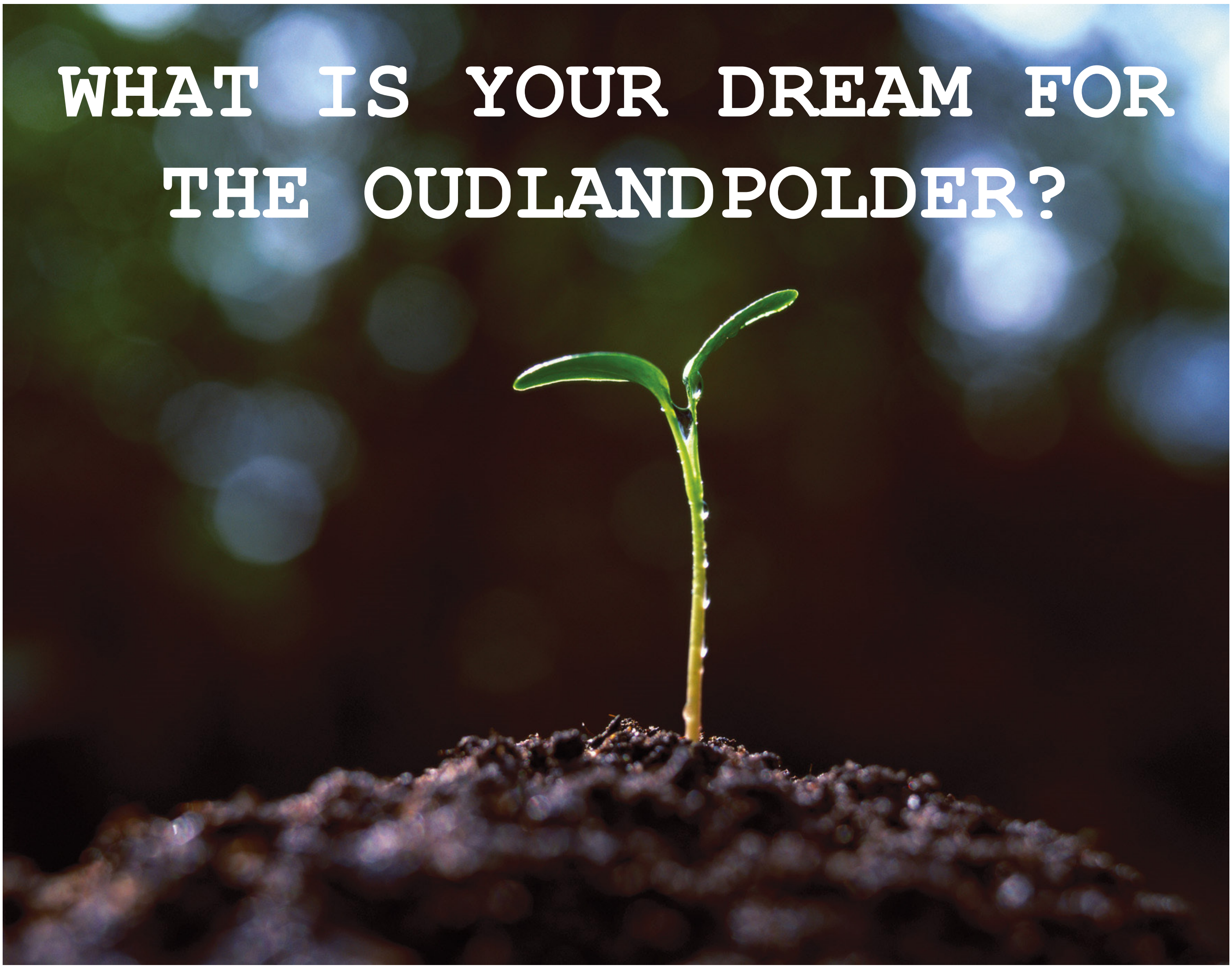
- The implementation of a climate adaptive water management system in the Oudlandpolder.
- The development of dedicated spatial plans marking out essential agricultural and natural structures in the Oudlandpolder.
- The organization and establishment of spatial preconditions allowing for the development of sustainable farming practices in the Oudlandpolder.
- The realization of polder related nature conservation targets in the Oudlandpolder.

This **framework agreement will be implemented by means of** several interlinked spatial planning processes, studies and operational projects assembled by the responsible authorities in **the land development project Oudlandpolder**, coordinated by the Flemish land agency (VLM) – one of the COASTAL partners. This project was **officially launched on December 18, 2020 by the Flemish government**. It involves a diversity of actions throughout the Oudlandpolder supporting the transition towards climate resilient water management, robust ecosystems, sustainable agriculture, vibrant polder villages and sustainable mobility. For this land development project a budget has been allocated of, in total, about 53 million EUR. It is supervised by an official planning guidance group established by the Flemish government.

The **scenarios** that are presented in this report, are developed in collaboration with the VLM and several thematic experts, among which also representatives of the Oudlandpolder planning guidance group. They consist of **narratives and figures explaining the uncertain evolution of several factors external to the Oudlandpolder** system we modelled, such as changes in land use, population growth or (technological) developments in urban water management systems, hence factors going beyond the control of the people involved in the Oudlandpolder's development at a local and regional scale. Notwithstanding this, these external evolutions may impact the development of the Oudlandpolder.

That is why we tried to come to a clear understanding of their true nature, and linked them to the Oudlandpolder's SD model. The latter implies that we scaled down these external uncertainties to the level of the modelled system and defined input variables where these external uncertainties connect with the processes giving rise to the Oudlandpolder's internal functioning.

Complementary to our modelling work, we initially started with a broader scenario development exercise that also covers themes going beyond the scope of the SD model. This way, we had access to a set of scenarios visualizing the future of the Oudlandpolder, both in narratives and pictures, that we could use to feed the ongoing stakeholder process discussing the future development of the region. These narratives were made accessible to interested parties through the publication repository of the Flemish government (cfr. this link). (An English version of this publication is available through COASTAL's knowledge exchange platform via this link.) In practice this means that the scenarios were used to feed the co-creation process supporting a broad group of stakeholders in the Oudlandpolder to develop shared 'guidelines' for the future development of their region. At the same time, the scenarios also functioned as a reference point to assess the impact and consequences of the shared development principles the stakeholders came up with. (Both these shared principles and the assessments can be found in the publication 'Signposts for a sustainable Oudlandpolder', which is also openly accessible via the online repositories just mentioned.)



EXPERT INVOLVEMENT DURING THE SCENARIO BUILDING PROCESS

PROJECT PARTNERS

Throughout the scenario development process several organisations were consulted to review the scenarios, and hence to correct and/or supplement them with additional information when needed. Representatives of the following COASTAL partner organizations gave input to the scenarios:

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Flemish Land Agency (VLM): coordinator of the Oudlandpolder land development project	Executive Agency of the Flemish government	rural development, land development	3	2	1	
VITO	Independent Flemish research organization	sustainable water management, spatial planning, societal transitions	2	1	1	

OTHER EXPERTS

In order to cover all needed expertise, also representatives of other organizations were consulted. Their details are summarized here:

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Departement Omgeving	Public administration	Spatial planning	2	1	1	
Agency for Nature and Forestry (ANB)	Public administration	Nature conservation and development	1	1		
Research Institute for Nature and Forestry (INBO)	Research Institute	Nature conservation and development	1	1		
Research Institute for Agriculture, Fisheries and Food (ILVO)	Research Institute	Agriculture, Aquaculture, Fisheries and Food systems	1	1		
University of Ghent	Research Institute	Agricultural Innovations	1	1		
Province of West-Flanders	Public administration	Agriculture	2	2		
Inagro	Research Institute	Agriculture	2	1	1	

RATIONALE EXPERT SELECTION

A draft version of the scenarios was created by the core team leading the Oudlandpolder case in COASTAL, that is VITO in collaboration with the VLM. In a next step, this draft version was reviewed and complemented with additional information by external experts. The latter were chosen in the first place based on their expertise. However, they also helped to increase the legitimacy of the scenarios.

APPROACH

The scenarios were developed over the course of a year (March 2020 – March 2021) by means of desk research, email conversations, one-on-one meetings and telephone calls, as well as discussions taking place in larger settings. The overview below gives a summary of the main meetings that took place in this course of events.

In addition to these meetings, part of the scenarios were also discussed during other events organized in the context of the COASTAL project, for instance in relation to the work that had to be done for WP3 (policy and business roadmaps) or WP4 (model development). The majority of the work, however, has been done by desk research due to the (severe) restrictions caused by the Corona pandemic and is reflected in numerous email exchanges.

1	Meeting with	VLM
	When?	March 3, 2020
	Main goal	Taking the first decisions concerning the direction to go with the Oudlandpolder case.
2	Meeting with	VLM
	When?	June 23, 2020
	Main goal	Discussing the main lines in the narratives of the scenarios in order to be able the progress with the calculations done by the Spatial Model Flanders.
3	Meeting with	INBO
	When?	November 12, 2020
	Main goal	Discussing the potential of wetland restoration in the Oudlandpolder.
4	Meeting with	VLM & Departement Omgeving
	When?	November 17, 2020
	Main goal	Discussing categories of land use in the Oudlandpolder.
5	Meeting with	ILVO
	When?	November 20, 2020
	Main goal	Discussing the potential of saline agriculture in the Oudlandpolder.
6	Meeting with	VLM, Departement Omgeving & ANB
	When?	December 7, 2020
	Main goal	Workshop to discuss the guiding elements in the land use scenarios for the Oudlandpolder.
7	Meeting with	VLM
	When?	February 4, 2021
	Main goal	Discussing elements that should be changed in the agricultural parts of the scenarios based on the review of the agricultural expert of the VLM.
8	Meeting with	VLM
	When?	February 5, 2021
	Main goal	Discussing elements that should be changed in the nature parts of the scenarios based on the review of the nature expert of the VLM.
9	Meeting with	University of Ghent
	When?	February 23, 2021
	Main goal	Discussing elements that should be changed in the agricultural parts of the scenarios based on the review of the agricultural expert of the University of Ghent.

10	Meeting with	Province of West-Flanders
	When?	February 24, 2021
	Main goal	Discussing elements that should be changed in the agricultural parts of the scenarios based on a review of the agricultural experts of the Province of West-Flanders (part 1).
11	Meeting with	ANB
	When?	March 3, 2021
	Main goal	Discussing elements that should be changed in the nature parts of the scenarios based on the review of the expert of the Agency for Nature and Forestry.
12	Meeting with	Province of West-Flanders
	When?	March 10, 2021
	Main goal	Discussing elements that should be changed in the agricultural parts of the scenarios based on a review of the agricultural experts of the Province of West-Flanders and INAGRO (part 2).

THE SCENARIOS IN RELATION TO THE OUDLANDPOLDER MODEL

As the scenarios for the Oudlandpolder deal with uncertainties *external* to the modelled system, they cannot be understood correctly without knowing the exact delineation of this system. What is 'in'? And what is 'out'? What is part of the modelled system? And what is not? This section therefore gives a brief introduction to the system dynamics model developed for the Oudlandpolder. Next, an overview is given of the uncertainties in the system's environment that were taken as a starting point to develop the scenarios.

WHAT DID WE MODEL?

In the context of COASTAL, we choose to focus in our SD model on a selection of land planning and management challenges that will most probably have an impact on the Oudlandpolder's water management system. The model therefore combines insights on the functioning and dynamics of the polder's water system with an agricultural component and spatial planning processes. The latter is done with the help of the Spatial Model for Flanders and allows to include spatial projections concerning the expansion of nature area and a decrease of agricultural lands, as well as urbanisation dynamics.

The spatial challenges that can be answered with the Oudlandpolder SD model, can be summarized by means of the following questions:

- Suppose that the agricultural businesses in the Oudlandpolder gradually adopt less water-intensive crop schemes, and hence choose to plant crops demanding less water during dry summer months, will the region then retain enough rainwater under all climate scenarios with the current polder canal system to cover water demand from both nature and agriculture?
- Suppose that the water system in the Oudlandpolder becomes decoupled from the canal Brugge-Oostende, which currently feeds the polder with considerable amounts of fresh water, how much buffering capacity should then be developed to retain enough rainwater in the region to meet the water demand from nature and agriculture?
- Suppose that, due to sea level rise, gravitional discharge of the Oudlandpolder is not possible anymore, what size of polder drainage pools and pumping capacity will then be needed?

More detailed information about the SD model's structure, its variables and associated quantitative information is reported about in the COASTAL deliverable D14 and deliverable D16. Both publications are accessible via the COASTAL website.

WHAT KIND OF EXTERNAL UNCERTAINTIES WERE TAKEN INTO ACCOUNT?

As has been explained in the introductory part of this report, the Shared Socio-economic Pathways, complemented with the Representative Concentration Pathways (RCPs), were used as a common starting point to develop the model-specific scenarios. In the table below, an overview is given of the parameters from this generic framework identified as being system external uncertainties that may affect the behaviour of the model described above. The second column displays the input variables where the scenarios connect with the modelled system. The third column lists the parameters from the generic scenario framework that were taken into consideration to explain the future evolution of these model-specific input variables.

N°	Model input variable	System-external uncertainties affecting this model input variable
1	Area agriculture	Population growth; urbanization level; land use
2	Area nature	Population growth; urbanization level; policy orientation; land use
3	Waste water treatment plant (WWTP) effluent available for polder	Population growth; urbanization type; policy orientation; technology transfer; resource use
4	Sea level rise	Climate change
5	Precipitation	Climate change
6	Reference evapotranspiration	Climate change

DETAILED DESCRIPTION OF THE SCENARIOS

In total, we developed 4 scenarios for the Oudlandpolder. Each of them is rooted in the combination of a SSP with a climate scenario corresponding with a certain RCP. We choose to work with SSP-RCP combinations that are frequently used in publications of the Intergovernmental Panel on Climate Change (IPCC) and other climate-related studies. This way, inter-study comparisons and meta-analyses will be easier to perform. We named our scenarios as follows, and linked them to the following SSPs and RCPs:

- **Sustainability**: SSP1 + RCP2.6
- **Not choosing is losing**: SSP2 + RCP4.5
- **Structural inequality**: SSP4 + RCP6.0
- **Technological optimism**: SSP5 + RCP8.5

In the remaining part of this section, the future evolution of each of the model input variables listed in the table above is described qualitatively. The quantitative data corresponding with these descriptions can be accessed via this link to the online data repository. To develop these region-specific scenario descriptions the following steps were taken:

- **Step 1** – All spatially explicit data were calculated making use of the Spatial Model for Flanders. This model was fed with land use projections coupled to different land use dynamics that were outlined during previous spatial planning studies for the Flemish government. In addition to this, the stakeholder process described above resulted in context-specific information that allowed to finetune these model projections to the characteristic dynamics of the Oudlandpolder.
- **Step 2** – To calculate the climate related data needed to feed the model, the Norwegian Earth System Model (NorESM1-M) was used (Bentsen, 2013[1]; Iversen, 2013[2]).
- **Step 3** – Population growth estimates were downloaded for each of the SSPs from the SSP Database developed by the International Institute for Applied Systems Analysis (IIASA). These figures were downscaled to the Oudlandpolder by means of the Spatial Model for Flanders.
- **Step 4** – The expected evolution in the amount of waste water treatment plant (WWTP) effluent under each of the SSPs was calculated based on a model developed by VITO water experts. This model assesses the consumption of tap water, grey water and rainwater in function of an increase in water use practices contributing to water use efficiency and the closure of water cycles. It allows to calculate the fraction ultimately ending up in a WWTP of the tap -, grey - and rainwater that was initially used.

[1] **Bentsen**, M., Bethke, I., Debernard, J. B., Iversen, T., Kirkevåg, A., Seland, Ø., Drange, H., Roelandt, C., Seierstad, I. A., Hoose, C., and Kristjánsson, J. E.: The Norwegian Earth System Model, NorESM1-M – Part 1: Description and basic evaluation of the physical climate, Geosci. Model Dev., 6, 687–720, https://doi.org/10.5194/gmd-6-687-2013, 2013.
[2] **Iversen**, T., Bentsen, M., Bethke, I., Debernard, J. B., Kirkevåg, A., Seland, Ø., Drange, H., Kristjansson, J. E., Medhaug, I., Sand, M., and Seierstad, I. A.: The Norwegian Earth System Model, NorESM1-M – Part 2: Climate response and scenario projections, Geosci. Model Dev., 6, 389–415, https://doi.org/10.5194/gmd-6-389-2013, 2013.

1&2. AREA AGRICULTURE & AREA NATURE

SUSTAINABILITY

This scenario includes the anti-urban sprawl land use scenario for Flanders. 'Anti-urban sprawl' not only tries to reduce the extra land take in Flanders to 0 ha by 2035, but also to make extra space over time for nature, agriculture and forestry. This results in a relatively large densification of villages, towns and cities. What the impact would be on the area of land dedicated to agriculture of the implementation of this kind of land use strategy in 2050, can be seen on this map of the Oudlandpolder.

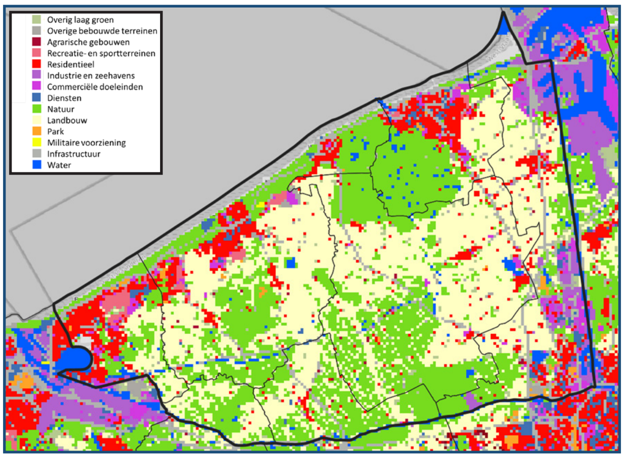


Figure 1. Land use in the OudlandPolder in 2050 according to the Spatial Model Flanders under the land use scenario 'anti urban sprawl'.

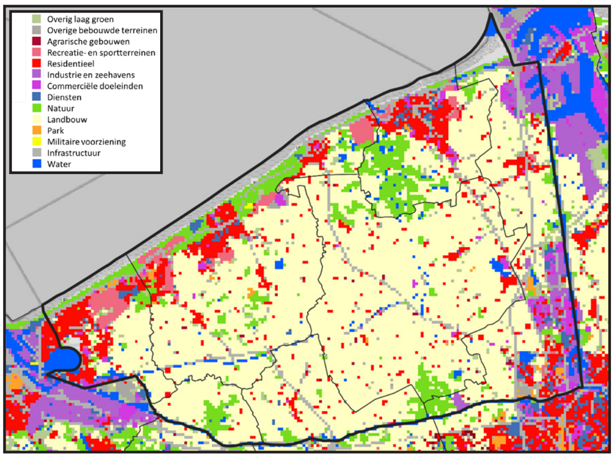


Figure 2. For comparison: Space use in the Oudlandpolder in 2013.

NOT CHOOSING IS LOSING

This scenario includes the 'business as usual' land use scenario. In this scenario, land use will increase in proportion to population growth. Relatively speaking, more housing, commercial premises, restaurants, etc. are added in the centres of villages and cities than in the outlying area. Compared to growth as usual (the land use scenario applied in the next scenario), the densities in village and city centres are therefore higher in this scenario.

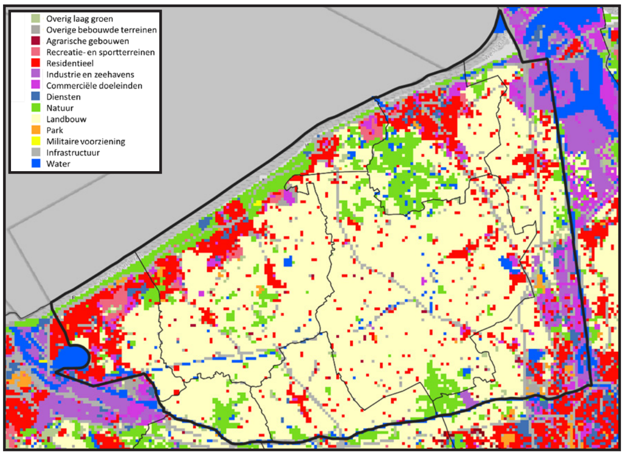


Figure 3. Land use in the OudlandPolder in 2050 according to the Spatial Model Flanders under the land use scenario 'business as usual'.

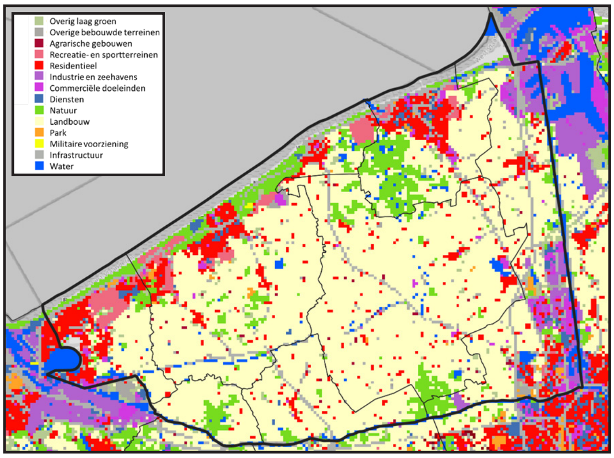


Figure 4. For comparison: Space use in the Oudlandpolder in 2013.

STRUCTURAL INEQUALITY

In this scenario, open space continues to be occupied at the current rate in Flanders. This means that every day about 6 ha of open space disappear. In this scenario you can therefore see a strong increase in the area of residential land.

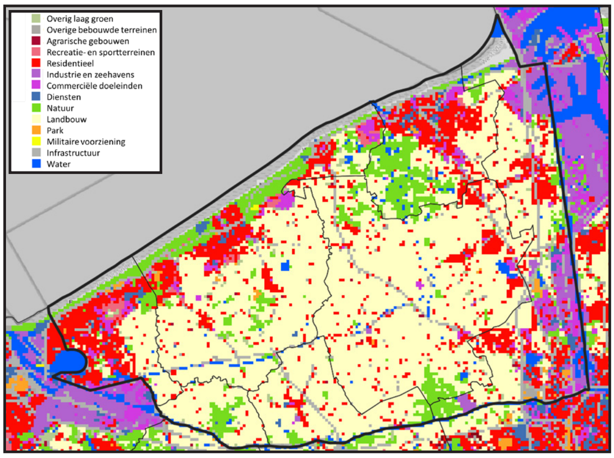


Figure 5. Land use in the OudlandPolder in 2050 according to the Spatial Model Flanders under the land use scenario 'anti urban sprawl'.

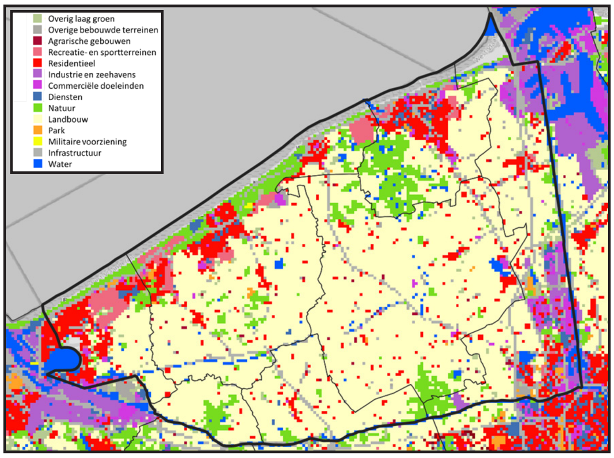


Figure 6. For comparison: Space use in the Oudlandpolder in 2013.

TECHNOLOGICAL OPTIMISM

This spatial scenario assumes strong densification based on the strategic spatial vision for Flanders (approved on July 13, 2018). The main objective of this vision is to reduce the growth in land take to 0 ha per day by 2040. This leads to the densification of city and town centres and well-located locations, namely locations with a high 'node value' and a high level of amenities.

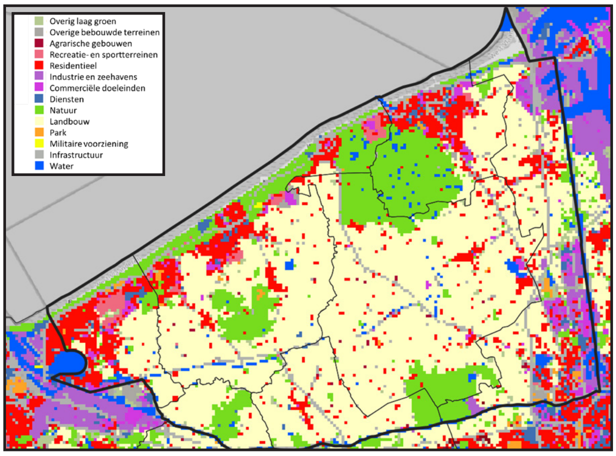


Figure 7. Land use in the OudlandPolder in 2050 according to the Spatial Model Flanders under the land use scenario 'strategic spatial vision Flanders'.

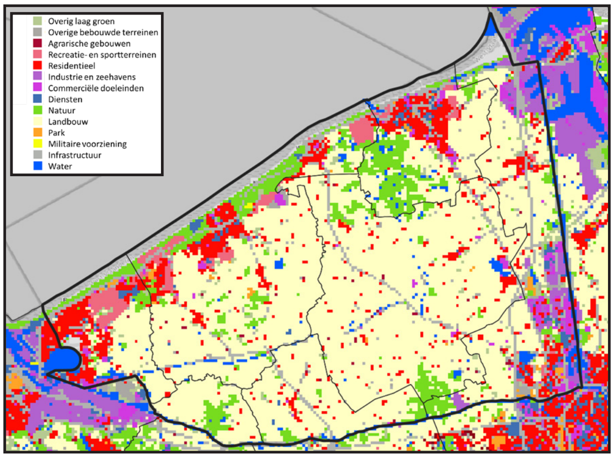


Figure 8. For comparison: Space use in the Oudlandpolder in 2013.

3. WASTE WATER TREATMENT PLANT EFFLUENT AVAILABLE FOR POLDER

Currently, the Oudlandpolder's water system is fed on a daily basis with about 70.000 m^3 of waste water treatment (WWTP) plant effluent. Due to a diversity of factors, among which technological developments leading to a more efficient use of (rain)water and attempts to close water loops, this amount of water is expected to decrease in the future. In order to be able to make an adequate estimation of this decrease, we quantitatively modelled the amount of waste water produced by four types of households:

1. households only using tap water - no implementation of additional water efficiency measures
2. households in which rainwater amounts to 33% of their water use - no implementation of additional water efficiency measures
3. households in which rainwater amounts to 32% of their water use - implementation of additional water efficiency measures as a result of which overall water consumption is lower
4. households optimally closing water loops resulting in grey water use amounting to 14% of their water use - rainwater representig 50% of their water use - no implementation of additional water efficiency measures
5. households optimally closing water loops resulting in grey water use amounting to 9% of their water use - rainwater representing 50% of their water use - implementation of additional water efficiency measures as a result of which overall water consumption is lower

The scenarios below show different proportions of these types of households.

SUSTAINABILITY

The proportions of the different types of households in this scenario are as follows in 2050:

1. (0%) households only using tap water - no implementation of additional water efficiency measures
2. (0%) households in which rainwater amounts to 33% of their water use - no implementation of additional water efficiency measures
3. (40%) households in which rainwater amounts to 32% of their water use - implementation of additional water efficiency measures as a result of which overall water consumption is lower
4. (0%) households optimally closing water loops resulting in grey water use amounting to 14% of their water use - rainwater representig 50% of their water use - no implementation of additional water efficiency measures
5. (60%) households optimally closing water loops resulting in grey water use amounting to 9% of their water use - rainwater representing 50% of their water use - implementation of additional water efficiency measures as a result of which overall water consumption is lower

In total, these changes in water consumption and management lead to an overall reduction of the amount of waste water of 41% compared to today. Furthermore, this scenario also incorporates a population growth based on the SSP1 growth projections for Belgium available in the IIASA database.

NOT CHOOSING IS LOSING

The proportions of the different types of households in this scenario are as follows in 2050:

1. (39%) households only using tap water - no implementation of additional water efficiency measures
2. (0%) households in which rainwater amounts to 33% of their water use - no implementation

of additional water efficiency measures

3. (50%) households in which rainwater amounts to 32% of their water use - implementation of additional water efficiency measures as a result of which overall water consumption is lower
4. (0%) households optimally closing water loops resulting in grey water use amounting to 14% of their water use - rainwater representig 50% of their water use - no implementation of additional water efficiency measures
5. (11%) households optimally closing water loops resulting in grey water use amounting to 9% of their water use - rainwater representing 50% of their water use - implementation of additional water efficiency measures as a result of which overall water consumption is lower

In total, these changes in water consumption and management lead to an overall reduction of the amount of waste water of 5% compared to today. Furthermore, this scenario also incorporates a population growth based on the SSP2 growth projections for Belgium available in the IIASA database.

STRUCTURAL INEQUALITY

In this scenario waste water processing becomes privatized. As a result of a growing demand for process water in industrial environments, the WWTP effluent is further processed and upgraded and eventually sold as process water. There is no WWTP effluent flowing into the polder anymore.

TECHNOLOGICAL OPTIMISM

The proportions of the different types of households in this scenario are as follows in 2050:

1. (0%) households only using tap water - no implementation of additional water efficiency measures
2. (20%) households in which rainwater amounts to 33% of their water use - no implementation of additional water efficiency measures
3. (0%) households in which rainwater amounts to 32% of their water use - implementation of additional water efficiency measures as a result of which overall water consumption is lower
4. (80%) households optimally closing water loops resulting in grey water use amounting to 14% of their water use - rainwater representig 50% of their water use - no implementation of additional water efficiency measures
5. (0%) households optimally closing water loops resulting in grey water use amounting to 9% of their water use - rainwater representing 50% of their water use - implementation of additional water efficiency measures as a result of which overall water consumption is lower

In total, these changes in water consumption and management lead to an overall reduction of the amount of waste water of 34% compared to today. Furthermore, this scenario also incorporates a population growth based on the SSP5 growth projections for Belgium available in the IIASA database.

4. SEA LEVEL RISE

The scenarios covering sea level rise projections are based on data provided for by the Intergovernmental Panel on Climate Change Working Group I in Chapter 9 ‘Ocean, cryosphere and sea level change’ of Assessment Report 6. More precisely in Chapter 9.6.3.3 ‘Sea-level projections to 2150 based on SSP scenarios.’ The graph below shows the different sea level rise trajectories that were taken into account in the modelling work for the Oudlandpolder.

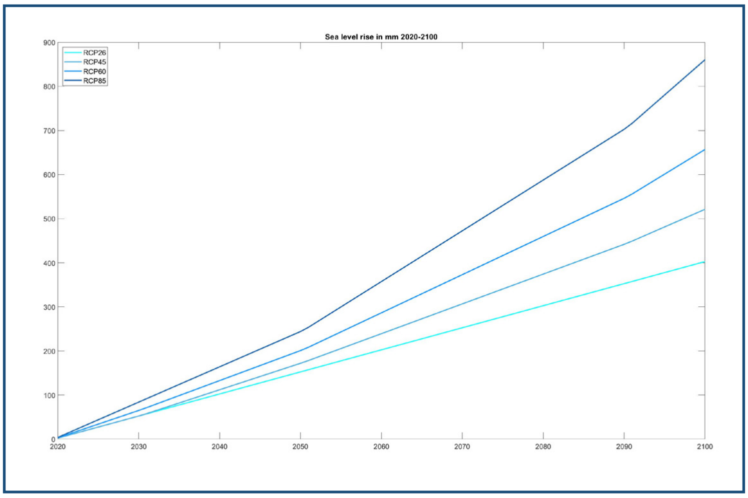


Figure 9. IPCC Working Group I sea level rise trajectories taken into account in the Oudlandpolder model.

5. PRECIPITATION

The average precipitation rate in the Oudlandpolder is currently estimated at 1045 mm/year. Due to climate change, however, precipitation patterns are expected to change. In general, model projections indicate that summer months will become dryer and winter months more wet. The more severe the climate scenario is, the more pronounced this phenomenon is expected to be. The graph below gives an indication of the expected evolution for the Oudlandpolder.

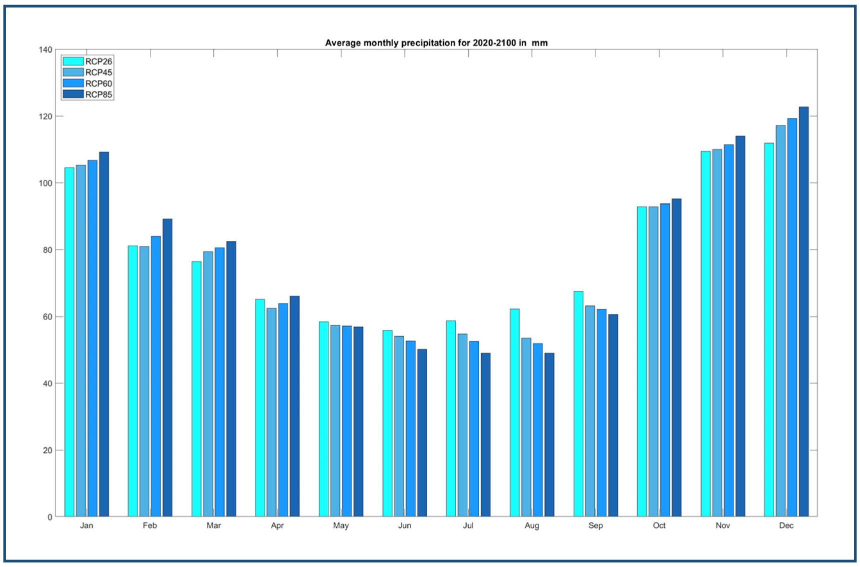


Figure 10. Average expected monthly precipitation over the period 2020-2100.

6. REFERENCE EVAPOTRANSPIRATION

Water demand in the Oudlandpolder is calculated for both nature and agriculture based on the potential evapotranspiration. This is the sum of (1) the evaporation of all water in and on soils and plants, and (2) the transpiration of water by plants. Evapotranspiration equals the total volume of rainwater ultimately going back to the atmosphere.

The potential evapotranspiration stands for the evapotranspiration happening when plants have access to enough water. In situations of water shortage the actual evapotranspiration will therefore be lower than the potential evapotranspiration. To calculate the potential evapotranspiration we followed the methodology proposed by the FAO (accessible via this link).

The figure belows shows the evolution of the potential evapotranspiration under several climate scenarios throughout the 21th century.

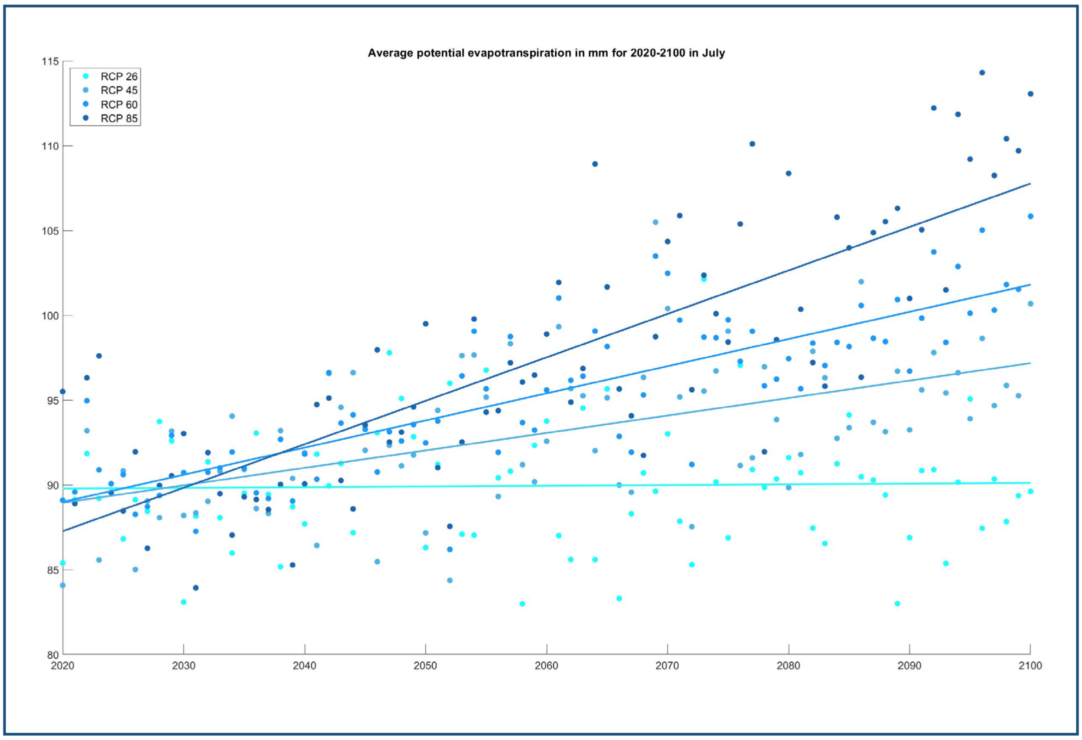


Figure 11. Evolution of the total potential evapotranspiration in the Oudlandpolder during the 21th century under different climate scenarios.

COMPARISON OF THE DYNAMIC PATTERNS OF KEY PERFORMANCE INDICATORS

Notwithstanding the vast amount of work that has been invested in the Oudlandpolder SD model during the COASTAL project, we unfortunately did not reach the point at which this tool can generate reliable output. Based on the latest test runs we had to conclude that the dynamic relation between surface and ground water levels in the polder should be further optimized. However, in the final stages of the COASTAL project we lack time and resources to complete this task. As a result, it's not possible, at the moment of writing, to present reliable results on the dynamic patterns of key performance indicators that can support decision making in function of the spatial development of the Oudlandpolder.

SCENARIOS FOR SOUTH-WEST MESSINIA

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COASTAL
Collaborative Land-Sea Integration Platform

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CONTEXTUAL ELEMENTS INFLUENCING SCENARIO BUILDING

The vision developed by the stakeholders of South-west Messinia is based on the ideal of achieving a sustainable and balanced interaction with the environment through processes that are dynamic and allow the system to be resilient to external and internal pressures and shocks. In order to develop strategic policy guidelines and business solutions supporting the pathways towards this resilient future, it is important to be able to measure the system's vulnerability to shocks, to identify possible tipping points and to explore barriers and drivers for transformation. Scenarios are useful tools to explore possible futures and to identify opportunities and threats in order to achieve this desired goal.

The coastal part of the South-west Messinia case study is designated as a NATURA 2000 area. However, due to a lack of environmental management several habitats of the site are under pressure (Maneas et al., 2019). When the COASTAL project begun, in 2018, there was no acting environmental Management Body in the area. In 2019, a Management Body was established, though along the way the status of this body changed again due to shifts in national policy. At present, the state is about to finalize the consultation process of the updated Special Environmental Study (SES) for the area and to assign the management of the site to a public Management Body.

Thus, to support the environmental management of the area, the scenario building process aimed to also provide suggestions for the management of the Gialova Lagoon, which is the coastal wetland which has been degraded by past anthropogenic activities and is in urgent need of measures for its restoration (Maneas et al., 2019; Maneas et al., 2020, Bray et al 2022). Moreover, the restoration of the wetland is central to the vision developed by the stakeholders, as it was identified as essential to fishing and tourism activities and is linked to agricultural practices at a catchment scale.

The COASTAL outcomes are expected to support the overall management of the area. The local COASTAL partners, and in particularly NEO, are in close contact with the relevant national authorities (NECCA). Suggestions for enhanced monitoring and actions that will improve the water management of the wetland (restoration) have already been imported in the updated SES.

STAKEHOLDER INVOLVEMENT DURING THE SCENARIO BUILDING PROCESS

PROJECT PARTNERS

The scope of the modelling work for South-west Messinia was determined based on the outcomes of the first workshop organized in the context of the COASTAL project, as well as our current understanding (Bray et al., 2022; Maneas et al., 2019; Maneas et al., 2020; Manzoni et al., 2020; Berg et al., 2018; COASTALD33). The visionary exercise developed during that workshop also served as a baseline for building up the scenarios that are presented here. These scenarios were then further discussed and developed with local and regional project partners. Preliminary results were shared and discussed with all interested parties in a second workshop. The tables below give a more detailed view of the organizations involved.

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
TEMES SA	Tourism company	Tourism development	3	3		
Captain Vasilis Foundation (CVF)	Foundation	Sustainable agricultural development	3	3		
Development Agency of Messinia (DAM)	Anonymous company administrated by the sub-regional government of Messinia	Regional development	3	1	2	

OTHER STAKEHOLDERS

In order to cover all needed expertise, also other local and regional stakeholders were involved in the workshops. Their details are summarized in the table below.

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Sub-region of Messinia	Regional government	Agriculture and fishing	3	1	2	
Municipal Water Agency	Municipality	Water management	1	1		
Forestry Agency	Public sector	Forest management	2	2		
Ephorate of Archaeology	Public sector	Antiquities protection and management	1		1	
Management Body	Public sector	Environmental management	1	1		
Nileas	Local farmers' cooperative	Olive oil production	1	1		
Agricultural Cooperative Messinia Union	Farmers' union	Agriculture	1	1		
Ben Olive Mill	Olive mill	Olive oil production and agritourism	1	1		
Gialova Association of Enterprises	Local association	Local economy	2	2		

Organisation	Type of organisation	Expertise	Number of participants	M	V	X
Yialova Lagoon	Fish company	Fishing and sport-fishing	1	1		
Explore Messinia	Tourism company	Ecotourism	1	1		
University of Kalamata	University	Cultural management	1		1	
Hellenic Ornithological Society	NGO	Birds conservation	1	1		
Archelon	NGO	Sea turtle conservation	1	1		

RATIONALE STAKEHOLDER SELECTION

In South-west Messinia, the Greek case study, tourism expansion and associated infrastructure development, such as hotels, roads and airports, provide opportunities for diversified livelihoods, but also increase the pressure on agricultural land, water resources and the natural environment (Tiller et al., 2019; Maneas et al., 2019; Klein et al., 2014). The area produces olive oil of high quality. However, current circumstances, such as small parcels of land, the (un)willingness to cooperate and CAP eligibility criteria for direct support when adopting agri-environmental measures (Damianos and Giannakopoulos, 2002, Lastra-Bravo et al, 2015), have added limitations to the sustainable growth potential of the sector (D1: Tiller et al., 2019). Today, the production of olives is mainly based on conventional farming practices (e.g., tillage, use of pesticides, herbicides and synthetic fertilizers), which results in severe environmental degradation of coastal and marine areas (COASTAL D33; Berg et al., 2018).

The operation of pomace-mills, located in industrial zones outside the catchment area, should ensure that olive-mill's waste is not disposed in the environment, but are treated as useful by-products that are further processed to produce other types of olive-oil and products (D1: Tiller et al., 2019). Unfortunately, not all olive-mills follow the regulations and their operation impacts the environment. Meanwhile, the wetland is in a bad environmental state (Bray et al, 2022), and unless actions are taken towards the restoration of hydrological conditions and the enhancement of its ecosystem services, it is expected that it may soon collapse.

In summary, this Greek case study is led by the research institutes NEO/SU, and HCMR. Additionally, it includes TEMES SA, CVF and DAM, as well as the stakeholdes mentioned above and other parties that may benefit from the project's outcomes. NEO/SU is located in the case study area and has a wide network of stakeholders with whom they collaborate in research and educational projects. HCMR has a long tradition in marine and wetland research in the area. Futhermore, TEMES owns the biggest touristic development in the area, CVF is a foundation focusing on the sustainable development of agriculture in Messinia and DAM is a company of the sub-region of Messinia which has the responsibility, among others, to administrate LEADER projects in the Messinia region. Thus, the selection of our stakeholders was based on suggestions from each of these partners and was followed then by the snowballing method.

SCENARIO DEVELOPMENT APPROACH

The people who contributed to the scenarios for South-west Messinia were involved from the first COASTAL workshop on, which took place in June 2019. During that workshop, the participants were

Table 1. Overview of the main meetings in the scenario development process.

1	Meeting with	Nileas
	When?	2020
	Main goal	Discussions to improve our understanding about olive-oil production: cultivation practices, irrigation patterns, role of cooperatives, production & sales, farmers' well-being, etc.
2	Meeting with	Municipal Water Agency
	When?	2020
	Main goal	Discussions to improve our understanding about municipal water supply system and waste-water management.
3	Meeting with	University of Ioannina
	When?	2021
	Main goal	Discussions to improve our understanding about fish in lagoon environments and associated ecosystem services.
4	Meeting with	Municipality
	When?	2021
	Main goal	Discussions to improve our understanding about mosquito management and solid waste management.
5	Meeting with	Interviews with project partners
	When?	2021
	Main goal	In-depth semi-structured interviews to improve the narratives and projections of the SSPs at local level.
6	Meeting with	Consultancy assigned to implement the update of the SES (NERCO)
	When?	2021
	Main goal	In-depth discussions for the integration of suggestions for enhanced monitoring and actions that will improve the water management of the wetland (restoration) within the updated SES.

engaged in a visionary exercise, where they were asked to agree on a common goal. Next, they had to identify enablers and barriers to achieve this goal through a back casting exercise. This process formed the baseline of our scenario development approach. The resulting common goal or vision can be summarized as: "***Join forces in creating the Brand Name of Sustainable Messinia that expands across all sectors, activities and products***" (D1: Tiller et al., 2019).

In particular, the MAL participants suggested that priority actions should consider the elements below:

- Adoption of an **integrated and eco-friendly model of olive-oil production**.
- Adoption of a **sustainable (resilient) low-impact tourism** model to reduce the impacts of mass 3S (Sea, Sand, Sun) tourism.
- Enhancement of **environmental management in protected and sensitive areas including a better monitoring of natural resources**.
- **Improvement of solid and liquid waste management**.

During a second workshop, which took place in March 2020, the participants were further introduced into the concepts of scenarios and transition pathways. They were asked to prioritize actions that can enable the pursuit of the commonly defined vision, as well as possible adaptation measures to mitigate climate change. The discussions about actions and adaptation measures were useful to downscale the SSPs to the case area.

The restrictions due to the pandemic limited active interactions with the stakeholders, but the use of online questionnaires provided useful input for the scenario building process. When these restrictions were lifted, the case coordinators decided to have an additional in-person meeting to further validate scenario development, which took place in March 2021. During this additional meeting we were able to use the 3 Horizons framework and identified possible signs that stirr the area either towards a more sustainable pathway or towards the current business as usual model. We used these discussions to validate, revise or further inform the scenario storylines. Complementary to the inputs provided during these three workshops, the scenario building process also received inputs and insights during meetings with our partners and with local and scientific experts.

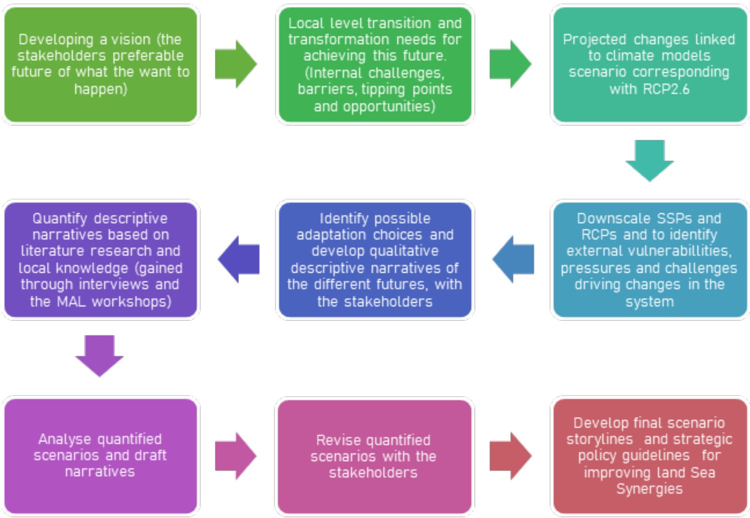

***Figure 1**: Overview of the scenario building process.*

THE SCENARIOS IN RELATION TO THE SYSTEM DYNAMICS MODEL

As the scenarios for South-west Messinia deal with uncertainties external to the modelled system, they cannot be understood correctly without knowing the exact delineation of this system. What is 'in'? And what is 'out'? What is part of the modelled system? And what is not? This section therefore gives a brief introduction to the system dynamics model developed within COASTAL for this area. Next, an overview is given of the external uncertainties in the system's environment that were taken as a starting point to develop the scenarios.

WHAT DID WE MODEL?

The system dynamics model for South-west Messinia covers an area of approximately 250 km^2, which is divided into four hydrological catchments. The model consists of several views (sub-models) that are separately developed and quantified, yet well interlinked. The model is designed to holistically address the main elements associated with the pursuit of the common vision for the area (cfr. previous section) under different scenarios and uncertainties (e.g. climate change, tourism development, restoration efforts, etc.). It is well connected to national and European policies. This means that concepts such as "ecosystem services", which is increasingly used within new EU strategies, are also incorporated in the model. (The detailed structure of the model is described in Viaene et al., 2020 and Viaene et al., 2021.)

In relation to the common vision of the area, some key topics and problems (and their interactions) that are addressed in the SW Messinia model 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 & agritourism). How is this beneficial for the farmers' well-being? And how can this be enhanced in the coming years (links with future projects and business opportunities)?
- The expected benefits of the transition (conventional to integrated/organic farming) on:
  - the environment (e.g. use of groundwater resources and salinization risk, use of chemical pesticides and fertilizers, water quality);
  - the characteristics of olive orchards (e.g. soil organic content, soil erosion, soil biodiversity, vegetation cover);
  - the well-being of farmers (e.g. costs for fertilizing and pest control, olive-oil price);
  - the branding and marketing of local products;
  - the attractiveness of the landscape and the promotion of agritourism.
- The effect of seasonal (mass) tourism on (and associated feedbacks):
  - the environment (e.g. use of groundwater resources and salinization risk, beach degradation);
  - 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 below:
  - biodiversity conservation and development of eco-tourism;
  - fish production and food security;
  - area attractiveness and tourism.

WHAT KIND OF EXTERNAL UNCERTAINTIES WERE TAKEN INTO ACCOUNT?

The SW Messinia SD model describes possible future shifts relative to the pursuit of the common vision for the region. These shifts will be partly determined by system external factors and uncertainties that cannot be controlled by actors active within the system, such as droughts and forest fires due to climate change or fluctuating energy prices. In the SD model these uncertainties are entered via scenarios built up from a combination of Shared Socio-economic Pathways (SSPs), complemented with insights from IPCC reports, and the Representative Concentration Pathways (RCPs).

The basic RCP used in the Greek model is RCP 2.6, as there were no climatic projections available conform an RCP1.5. Given the latest insights in the evoluation of climate change, this was not considered a major problem. Moreover, some researchers (Vautard et al., 2014; Koutroulis et al, 2916) expect that the Mediterranean temperature change will be at least one degree higher than the global average anyway. Additionally, we have also run the model against an RCP 8.5 to test the model's behaviour under extreme conditions.

To downscale the global SSPs to the case study level we made use of the narratives and projections developed by Reimann, Merkens and Vafeidis (2017) for the Mediterranean Coastal Zones. These narratives and projections were further specified based on the narratives developed by the case's stakeholders during workshops and other discussion moments. Further input came from the trends published by Mitter et al., 2020 in relation to the future of agricultural activities.

In the table below, an overview is given of the parameters from these scenarios that are expected to affect the future behavior of the modelled system. The second column displays the input variables where the scenarios connect with the modelled system. The third column lists the parameters from the generic scenario framework that were taken into consideration to explain the future evolution of these model-specific input variables.

***Table 2.** Model input variables in relation to system-external uncertainties.*

N°	Model input variable	System-external uncertainties affecting this model input variable
1	Precipitation, Evapotranspiration & Evaporation	Climate change
2	Cooperative Capacity	Agro-food policies, agro-food industry development, consumer choices, social equity and social cohesion
3	Water Demand	Population, technology, climate change, public and private investments and resource availability
4	Sustainable Food Production (Demand)	Population, global economy, energy costs, public and private investments, global social and environmental awareness
5	Coastal Tourism	Global economy, energy costs, technological advancements
6	Secondary Housing	Population, migration
7	Policy Implementation	National policies

DETAILED DESCRIPTION OF THE SCENARIOS

In total, we developed 4 scenarios for South-west Messinia. Each of them is rooted in the combination of a certain SSP with a climate scenario linked to a certain RCP. The following overview shows the combinations used during the scenario building process:

- Scenario 1 (SSP1 + RCP2.6): Green, integrated road
- Scenario 2 (SSP2 + RCP2.6): Unorganized, middle road
- Scenario 3 (SSP4 + RCP2.6): Divided road
- Scenario 4 (SSP5 + RCP2.6): Rapid development

In the remaining part of this section, future evolutions under each of these four scenarios are described qualitatively making use of each of the variables listed in the second column of Table 2 above. Via the following repository link all quantitative data corresponding with these qualitative descriptions can be accessed easily: https://zenodo.org/communities/773782-coastal/?page=1&size=20

1. CLIMATE VARIABLES: PRECIPITATION, EVAPOTRANSPIRATION & EVAPORATION

The climate variables that are used in the SD model for South-west Messinia, cover the precipitation (P), evapotranspiration (PET) and evaporation (E) rates. The variables "P-PET inland", "P-PET coastal" and "P-E lagoon" (inputs or outputs in m/Year), are used to describe the water exchanges with the atmosphere (see also Figure 2).

The variable "Tourism Climate Index (TCI)" is kept constant as we have assumed that, although there will be a reduction in summer arrivals due to an average temperature increase, there will most probably be an increase in arrivals during the rest of the year. Hence, the overall annual trend will not be affected. This decision is in line with what others have estimated for tourism in Greece, which is expected to be less vulnerable than other destinations (Koutroulis A., et al. 2018).

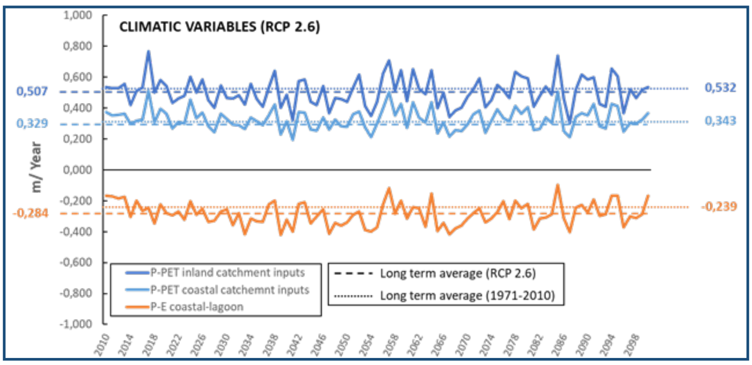

Figure 2*: Annual changes in climatic variables in the Greek case study, under RCP 2.6 (coastal areas as P-PET coastal) projected for different (RCPs) during the years 2010-2100. Long-term annual average precipitation for RCP2.6 is equal to 332 mm/yr, indicating a decrease of about 8,5% compared with the long-term annual average for 1971-2010 (362 mm/yr - Reference condition).*

2. VARIABLE: COOPERATIVE CAPACITY

"Cooperative capacity" is defined as the ability of partners in a partnership to collaborate towards the partnership's goals. It is a dimensionless parameter that affects the flow variable "willingness of farmers" directly, as more cooperation leads to an increase of the cooperative's membership. Partnership development is one of the main Sustainable Development Goals (SDG17), but its successful implementation is affected by both system internal and external factors, as a result of which it is recognized to be one of the main uncertainties for the system of Messinia. As a value it depends on (Vayaliparampil et al., 2021):

- The development of a common understanding or vision that includes a shared interpretation of the roles and processes in the partnership.
- The level of equity in shared governance roles and decision-making experienced by all partners within the partnership.
- The level of trust between the partners.

In addition, as we are referring to cooperatives based on sustainable agricultural practices, their cooperative capacity will also depend on policy choices in associated domains, such as agriculture, nature and economy, evolutions in the agri-food industry and consumer choices (Grashuis J., 2018).

Figure 3, which can be found on page 16, shows the expected evolution in cooperative capacity under each of the SSPs. The reference value for this variable is set at 0.2 and its maximum is 1.

Green, integrated road

Societies start to collaborate to achieve common goals and to form integrated partnerships (Vayaliparampil, et al., 2021). Global examples from successful collaborations are widely disseminated as pilot models for a sustainable future. Policies are supportive to sustainable and collaborative practices by means of financial support and the promotion of inclusive governance. Consumers select high-quality products and the agro-food industry supports sustainable farming. Equitable practices and autonomy build trust and understanding among farmers. Under this scenario, "cooperative capacity" increases rapidly, showing a mean increase of around 245% (from 0.200 to 0.690).

Unorganized, middle road

In this scenario partners have invested in a vision, though they often follow their own work plans. As a result, they tend to work only haphazardly towards the achievement of the vision (Vayaliparampil, et al., 2021). There is a reduced level of agency and equity under these circumstances, hence success is much more dependent on outside drivers, such as policies and supporting subsidies, making existing partnerships more vulnerable. A small percentage of farmers continues to collaborate. And if successful, these collaborations will attract more partners. Under this scenario, "cooperative capacity" increases slowly, showing a mean increase of around 61% (from 0.200 to 0.261).

Divided road

There is no clear vision. Farmers might work together when it suits their own interests and practices. As poverty is increasing and societies fragment more and more, there is no equity or governance shared among participants. European agricultural policies increasingly support economic growth and technology development, from which the large, industrialized farms benefit the most. The interests of a large proportion of society are mostly ignored (Mitter et al, 2020). Co-operatives and local agro-food initiatives are rare, as global agri-business players dominate the supply chains. Under this scenario, "cooperative capacity" is reduced significantly and shows a mean value of around 61% (from 0.200 to 0.078).

Rapid development

A dominant partner often dominates the vision, mission and strategy of cooperations, as a result of which partnerships are often dependent on the dominant partner's directives (Vayaliparampil, et al., 2021). The relationship between farmers and the rest of society is deteriorating because of a high degree of individualization and egocentrism (Mitter et al, 2020). Public payments to agricultural and food systems are drastically reduced conform the paradigms ruling liberalized and integrated markets. Environmental standards are lowered considerably, which results in an overexploitation of natural resources. Furthermore, people adopt new dietary habits based on technological advancements (Mitter et al, 2020), which causes a decrease in the global demand for olive oil. As a consequence, more and more farmers choose to sell their properties for built-up land. Under this scenario, the overall effect of these evolutions results in a gradual decrease of "cooperative capacity", showing a mean value of around 31% (from 0.200 to 0.139).

3. VARIABLE: WATER DEMAND

The current average annual domestic water consumption was estimated based on the historical average consumption of 288 L/day/capita. Global SSP scenarios do not provide any specific qualitative descriptions of possible future water demand, although it is expected that there will be an increase due to changes in climatic conditions (Koutroulis, et al 2016). The input variable "water demand" is a dimensionless parameter linked to the variables "per capita water demand" and "per tourism water demand". The reference value for this input variable is set at 1. Figure 3 (cfr. page 16) shows the expected evolution in water demand under each of the SSPs.

Green, integrated road

Under this scenario, there is a slight decrease in water demand, which is related to increased awareness and more efficient usage both in agriculture and in tourist facilities (Reimann et al, 2017; Koutroulis et al, 2016). This results in a slight decrease of the water demand, which is given a reference value of 1 to a mean value of 0.91.

Unorganized, middle road

Koutroulis et al., (2016) suggest that realistic future scenarios of irrigation demand are based on local development plans and proposed strategies for an expansion of the irrigation networks. Other information that was taken into account was any relevant information in the SSPs linked to the area of irrigated land and data about crop intensity. The overall conclusion was that water demand in this scenario 2 is affected more by internal system actions than external factors, and hence remains stable with regards to the SSP changes.

Divided road & Rapid development

Under these scenarios the private sector makes efforts to increase productivity and human well-being with new technologies, but focuses less on resource efficiency. As a result, lifestyles are more resource- and energy- intensive and resource demands rise. This results in increasing pressures on land, water, and biodiversity (Mitter, 2020). In both scenarios, the effect of water demand is therefore increased with 9% (from 1 to 1,09).

4. VARIABLE: SUSTAINABLE FOOD PRODUCTION (DEMAND)

The input variable “sustainable food production” is a dimensionless parameter linked to the variables “transition factors” and “local tourism demand for sustainable olive-oil production”, which are both part of the part of the model that describes interactions within the agricultural sector. The reference value for this input variable is set at 0.1. Figure 3 below shows the expected evolution in “sustainable food production” under each of the SSPs.

Green, integrated road

Under this scenario, the impact of sustainable food production is increased by 60% (from 0.1 to 0.16). This is because of consumer demands that favour the supply of multiple ecosystem services (Mitter et al., 2020), which goes along with more farmer engagement in the area. The demand for ecosystem services gives rise to a stable pace of structural changes in agriculture, also favoring producers and producer cooperatives.

Unorganized, middle road

Under this scenario, the degree of sustainable food production remains unchanged and equals 0.1. The demand for locally produced food, as well as for plant-based protein/meat alternatives, increases very slowly. Yet, because there is no organized support in the area, this has little impact. A large share of the population still consumes convenient and highly processed food. Minimum standards are set at the European level, but individual countries can decide on more rigorous standards. Their implementation depends on policy decisions (see also the scenarios covering policy implementation).

Divided road

Inequalities in education and income prevail in the agricultural sector. This results in a very diverse farming population in terms of age, education level, innovative capacity and migration background (Mitter et al 2020). Under this scenario, sustainable food production decreases by 30% (from 0.1 to 0.07).

Rapid development

European decision-makers have a strong interest in trade liberalization. In line with this paradigm they continue to strengthen and invest in multi-lateral trading systems at the global level. This further increases competition in the agricultural sector (Mitter, 2020). This liberalized agricultural model favours high-tech, large farming businesses and the consumption of processed food. It is difficult for small-scale producers to follow the trends of rapid development without financial support. As a result, sustainable food production decreases with 60% (from 0.1 to 0.04).

5. VARIABLE: COASTAL TOURISM

The input variable “coastal tourism” is a dimensionless parameter linked to the flow variable “new beds”, which is used to calculate the variable “tourism growth rate” and the stock “beds availability”. The latter gives the annual number of beds in the area (existing and new). The reference value for this input variable is set at 1, which in the model means that tourism will follow current growth rates (Viaene et al., 2021). Figure 3 (cfr. page 16) shows the expected evolution in coastal tourism under each of the scenarios.

The storylines of these scenarios were based on interviews with the main developer in the area (TEMES) and the study by Reimann et al. from 2016. Similar to the latter, we decided to follow the approach of not only considering the number of tourists arriving, but also the type of tourists visiting the area, and whether they would have an interest to diversify their activities instead of following the traditional 3S-model.

Green, integrated road

Under this scenario there is still an increase in the number of arrivals, though the growth rate is slightly reduced compared with current trends. The reason for this, is that people tend to choose destinations that are closer to their homes or where they can travel to by car. However, as the COVID restrictions have showed, a reduction in the number of flights, or even imposing a ban on flying for a number of months, has little to no impact on the number of people arriving in Messinia. It is not an island and therefore easy to reach by car. As a result, the most important change that can be expected, is a shift in the type of tourists. With the right investments, more and more tourists are expected to select this destination for its natural value and its adjacency to a Natura2000 site. Under this scenario, "coastal tourism" therefore gradually decreases with 12% (from 1 to 0.88).

Unorganized, middle road & Rapid development

Under both these scenarios the tourism sector continues to grow, showing a mean increase of this variable of around 61% (from 1 to 1.61). In the scenario "rapid development" also a significant increase is observed in the visitors opting for the 3S-model, as there is less interest in this scenario for high-quality tourism. In the scenario "unorganized, middle road", on the other hand, there is a continuation of current trends. This means that most tourists will still come to the area for its sandy beaches, yet certain groups will also show interest in the area's natural assets.

Divided road

Under this scenario coastal tourism increases with, on average, 31% (from 1 to 1.31). This implies a slower growth rate than in the former two scenarios. The reason for this is that tourism will continue to grow for the elites only, which means that one can expect a decline in mass tourism. However, as the area caters to the elite tourism growth rates are expected to remain high.

6. VARIABLE: SECONDARY HOUSING

The input variable "secondary housing" is a dimensionless parameter linked to the flow variable "new houses", which is used to calculate the stock "secondary houses". The latter gives the annual number of secondary houses in the area (existing and new). The reference value for this variable is set at 1. Figure 3 below shows the expected evolution in secondary houses under each of the scenarios.

Green, integrated road

Under this scenario agriculture gains more and more support, as a result of which the trend of land use changes towards private properties with secondary homes gradually comes to an end. Restrictive policies (Reimann, et al 2017) further inhibit the urbanisation of rural coastal areas. The value shows a mean decrease of around 61% (from 1 to 0.39).

Unorganized, middle road & Rapid development

Under both scenarios population growth in coastal rural areas of the north Mediterranean is mainly driven by tourism and second home ownership. The population in coastal areas increases because most economic activities are located, which results in a high urbanisation rate (Reimann, et al, 2017). A lack of spatial planning policies remains a major problem in these scenarios. There are not enough contstraints therefore to limit the building of secondary houses. Consequentially, the variable "secondary housing" increases with 61% (from 1 to 1.61).

Divided road

As in this scenario coastal development is driven by the interests of the elite, the coastal population is expected to further grow based on an influx of tourists and the expansion of areas for secondary homes (Reimann, et al, 2017). Under this scenario, the variable "secondary housing" is therefore increased with about 31% (from 1 to 1.31).

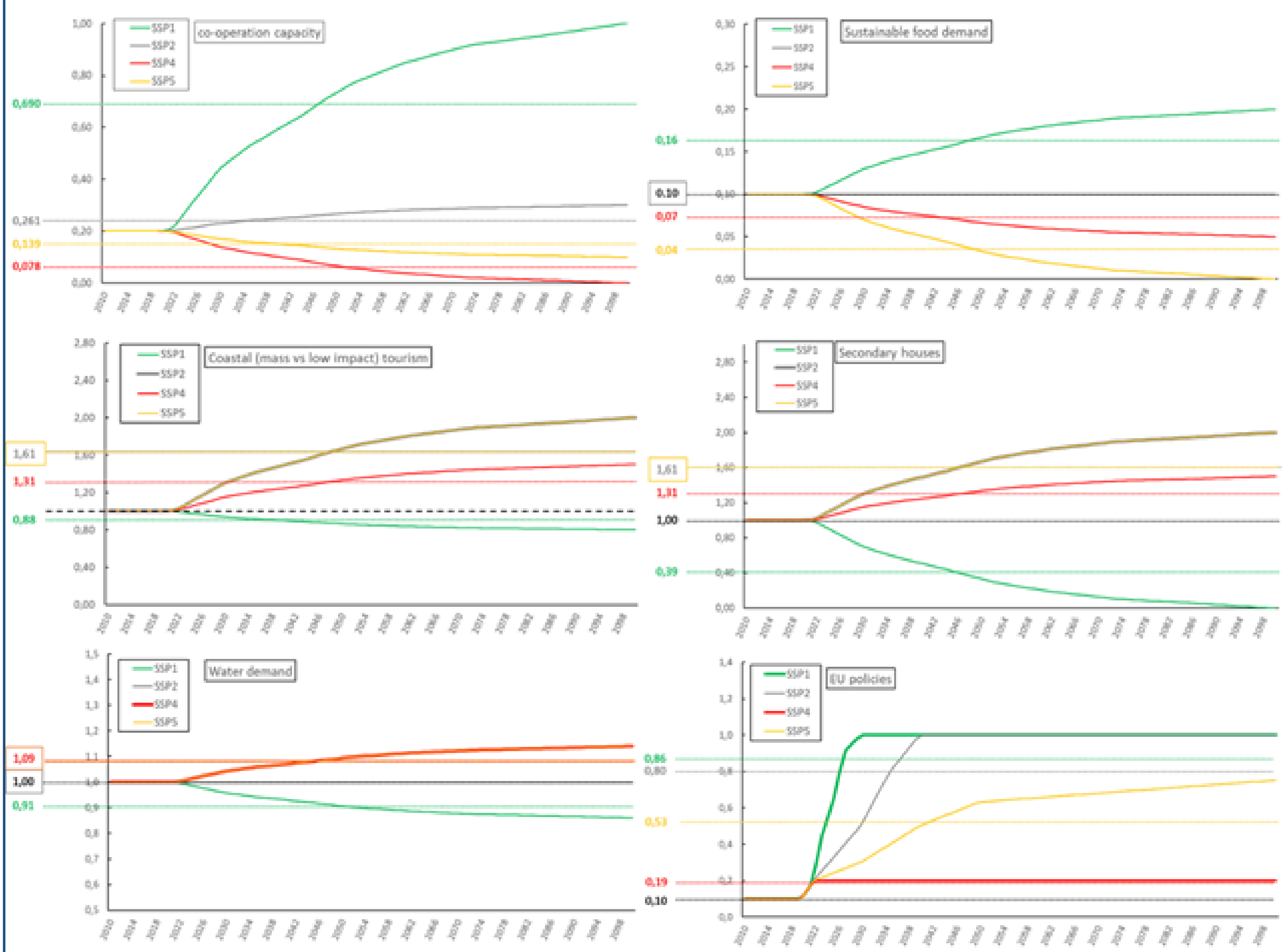

Figure 3: Modelled development of different scenario variables throughout the 21st century in South-west Messinia.

7. VARIABLE: POLICY IMPLEMENTATION

A key external variable in the SD model for this Greek case is the implementation of European policies at the national level and whether these policies can prevent a possible collapse of the lagoon system. Another point of discussion is whether these policies will support the development of the land use spatial plan for the area. Yet, these issues mostly apply in the short run as they are based on assumptions about the effective implementation of the most recent Common Agricultural Policy or the Biodiversity Strategy. It is not possible to predict possible future changes of these policies during the coming decades. However, we did try to include some relevant storylines covering these longer-term evolutions in the scenario descriptions presented on the previous pages. We added scenario lines for the implementation of the Common Agricultural Policy (CAP) as "EU policy implementation (CAP)" and for the NATURA 2000 framework as "EU policy implementation (NATURA)". These variables are linked to several variables within the SD model (cfr. Figure 4 below).

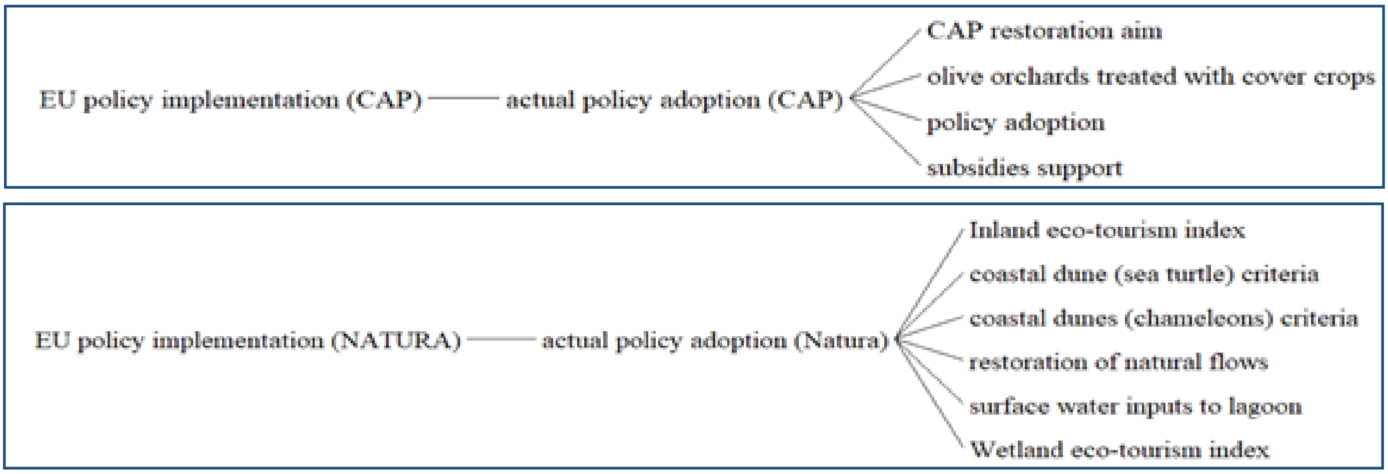

***Figure 4**: Links between European policies and variables in the SD model for the Greek case.*

The selected scenarios are expressed as the time needed for full adoption and implementation. They follow the same pattern. The reference value for both variables is set at 0.1 and the maximum at 1. Figure 3 (cfr. page 16) illustrates the expected implementation timeframe under each of the scenarios.

Green, integrated road
This scenario suggests that the relevant European policies will be adopted and will be fully implemented by 2030.

Unorganized, middle road
This scenario suggests that the European policies will be adopted with some delays and will be fully implemented by 2040.

Divided road
This scenario suggests that the adaptation of relevant European policies will fail and that they will not be implemented.

Rapid development
This scenario suggests that relevant European policies will be adopted with strong delays and that a full implementation status won't be reached by 2100.

COMPARISON OF THE DYNAMIC PATTERNS OF KEY MODEL VARIABLES

The integrated Greek SD model addresses the basic components of the common vision for South-west Messinia. For the selection of Key Performance Indicators (KPIs) we relied on European policies - the Water Framework Directive (WFD) and the Common Agricultural Policy (CAP) in particular - and broader European strategies associated with these policies, such as the Green Deal. Furthermore, the NATURA 2000 framework (NATURA) was a special point of attention, as well as the policy frameworks linked to it (e.g. the new European Biodiversity Strategy).

In this section we present the outcomes of selected KPIs in relation to:

Olive-oil production and Land Use:

- cooperative strength (Dmnl)
- GDP from olive-oil sales (Euros/Year)
- orchards under sustainable (integrated/organic) practices (ha)
- application of chemical fertilizers (%)
- Landscape Character Index (Dmnl)

Wetland restoration:

- groundwater abstractions (m^3/Year)
- groundwater availability for wetland restoration (m^3/Year)
- Mean Annual Salinity (g/Lt)
- lagoon collapse risk (Dmnl)
- biodiversity indices for vegetation, birds (Dmnl)
- potential fish catch (Kg/Year)
- expected tourists (Person/Year)

1: KPIs LINKED TO OLIVE OIL PRODUCTION AND LAND USE

The impact of the different scenarios on the variables that are used to describe olive oil production, is mainly seen via the variables "transition factors" and "changes in mentality", which directly link to the KPIs "cooperative strength" and "orchards under sustainable practices". This implies that they also affect the rest of the selected KPIs (cfr. Figure 5).

Having an in-depth look at the model outcomes one can observe that, when farmers join forces in co-operative schemes and adopt sustainable farming practices, the olive oil sector will benefit from improved branding and marketing, as well as from a reduction of chemical inputs and prudent water use. When compared to the 2011-2020 average annual value, we noticed the following under the different scenarios:

Green, integrated road

- The GDP from olive oil sales is expected to increase with 6% during the period 2041-2050 and with almost 22% during the period 2071-2080.
- The cultivation costs are expected to decrease with 2% during the period 2041-2050 and with almost 7% in the period 2071-2080.
- The application of chemical fertilizers is expected to increase with almost 3% during the years 2041-2050 and by almost 14% in the period 2071-2080.
- The water demand for irrigation is expected to increase with 1% during the years 2041-2050, yet to decrease with 4% during the period 2071-2080 when more farmers start to irrigate according to the trees' needs.

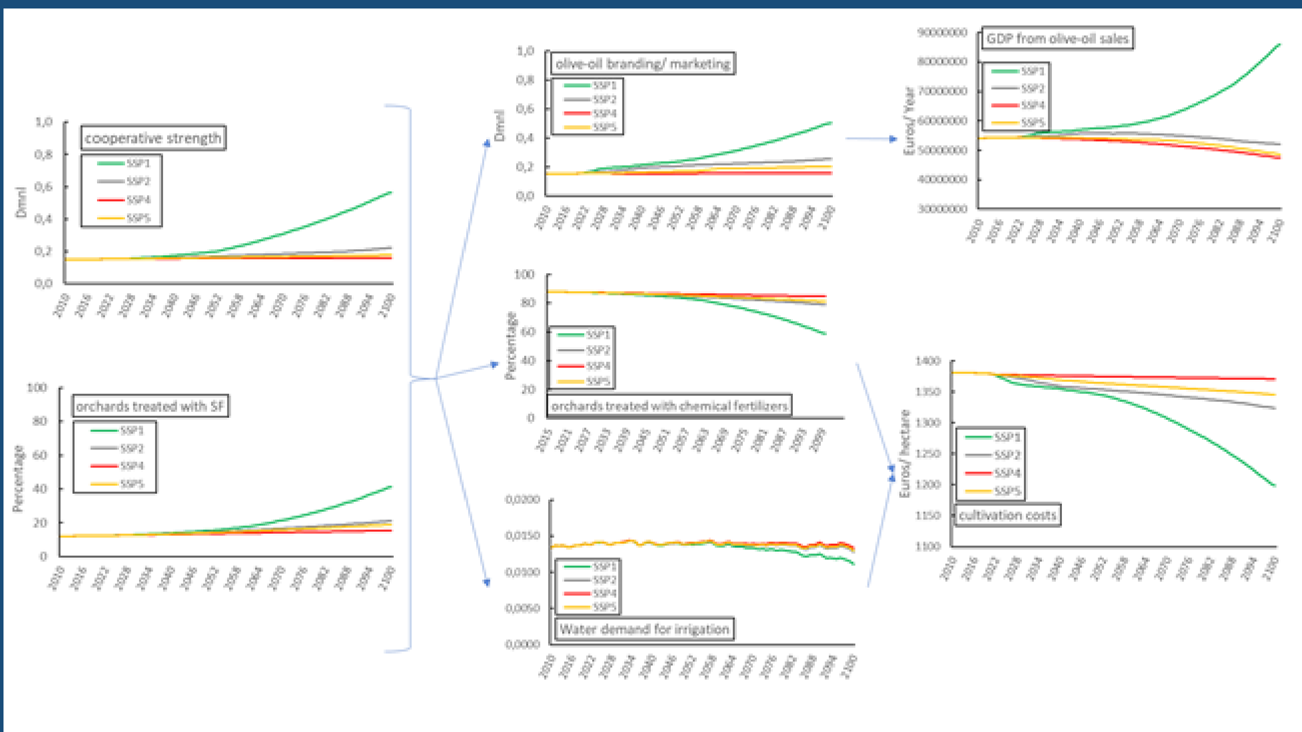

***Figure 5**: Modelling results for the KPIs linked to olive oil production in South-west Messinia.*

Unorganized, middle road

- The GDP from olive oil sales is expected to increase with about 3% during the years 2041-2050 and with 0,5% during the period 2071-2080.
- The cultivation costs are expected to decrease with 2% in the period 2041-2050 and with almost 3% during the years 2071-2080.
- The application of chemical fertilizers (% of land treated with chemical fertilizers) is expected to decrease with 2% by the middle of this century (2041-2050) and with almost 6% during the years 2071-2080. This decreasing trend is mainly a result of the loss of agricultural land in favor of build-up land (cfr. Figure 6 below).
- The demand for irrigation water is expected to increase with 2% during the years 2041-2050 and to decrease with 0,4% in the second half of this century (2071-2080).

Divided road

- The GDP from olive oil sales is expected to decrease with 1% during the years 2041-2050 and with 6% during the period 2071-2080.
- The cultivation costs are expected to decrease with 0,4% in 2041-2050 and with almost 0,5% during the years 2071-2080.
- The application of chemical fertilizers is expected to increase with 1% during the period 2041-2050 and with almost 3% during the years 2071-2080. This decreasing trend is mainly a result of the loss of agricultural land in favor of build-up land (cfr. Figure 6).
- The demand for irrigation water is expected to increase with 2% during the years 2041-2050, yet to decrease with 2% during the second half of the century (2071-2080).

Rapid development

- The GDP from olive-oil sales is expected to decrease with 0,3% during the years 2041-2050 and to further decline by almost 3% in the period 2071-2080.
- The cultivation costs are expected to decrease with 2% by the middle of the century (2041-2050) and to become even lower (a decrease of almost 6%) in the years 2071-2080.
- The application of chemical fertilizers is expected to increase with 2% during the years 2041-2050 and to increase even more with 5% during the second half of the century (2071-2080). This decreasing trend is mainly affected by the loss of agricultural land in favor of build-up land (cfr. Figure 6).
- The demand for irrigation water is expected to increase by 2% in 2041-2050 and to decrease

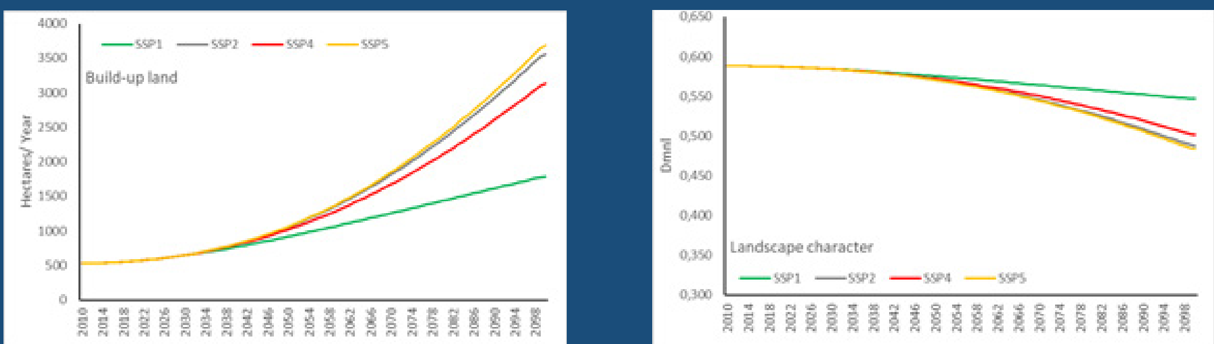

Figure 6*: Modelling results for the KPIs linked to olive oil production in South-west Messinia.*

by 1% later on (2071-2080) due to farmer practices aligning more and more with the irrigation needs of the trees.

2: KPIs LINKED TO WETLAND RESTORATION

The impact of the different scenarios on the variables that are used to describe wetland restoration, can mainly be noticed via the variables "restoration of natural flows" and "water availability", which both affect the variable "Mean Annual Salinity (MAS)". The MAS is considered as a central KPI within the model and it is connected to several other KPIs.

The compilation of graphs in Figure 7, illustrates how the delay in restoration actions could affect the wetland status (biodiversity: vegetation, birds' index) and the associated economic activities (fishing: fish catch and tourism: collapse risk, annual tourism).

In the model we assume that restoration efforts (reconnection with fresh water inputs from the catchment) can be realized once the EU policy index reaches a value of 0.58 (establishment, operational capacity, work preparation). Thus, under the scenarios "Green, integrated road", "Unorganized, middle road" and "Rapid development", the Mean Annual Salinity (MAS) is expected to decrease, be it during a different period in time. On the other hand, if the EU policy implementation remains only a paper effort, the MAS is expected to continue to increase and to reach values that are toxic for aquatic life. The model outcomes suggest that, the quicker the restoration works can start, the lower the impact on the biodiversity will be. The risk of a collapse of the ecosystem is expected to have an impact not only on the tourism sector, but also on the fishing industry in the region.

Under the scenario "**Green, integrated road**", a collapse of the system will most likely be avoided due to immediate actions to restore the wetland. This restoration effort will favor fishing and tourism. When compared to the 2011-2020 average annual value, we notice the following:

- The Mean Annual Salinity is expected to decrease by 22% in the years 2041-2050 and by almost 22% during the period 2071-2080.
- The fish catch is expected to increase with 56% during the years 2041-2050 and by almost 60% in the period 2071-2080.
- The vegetation index is expected to improve by 335% in the years 2041-2050 and by 391% in the period 2071-2080.
- The birds index is expected to improve with 39% in the period 2041-2050, but to decrease with approximately 41% during the years 2071-2080, as more farmers start to irrigate then according to the trees' needs.
- The risk of a collapse is expected to decrease with 82% in the period 2041-2050 and with 88% during the years 2071-2080.

Under the scenario "**Unorganized, middle road**", a collapse of the system can most probably not avoided anymore, due to delays in the implementation of wetland restoration actions. This will have serious implications on biodiversity, fishing and tourism. When compared to the 2011-2020 average annual value we notice the following:

- The Mean Annual Salinity is expected to decrease with 5% during the years 2041-2050 and with almost 24% during the period 2071-2080.
- The fish catch is expected to increase with 13% during the years 2041-2050 and with almost 60% in the second half of the century (2071-2080).
- The vegetation index is expected to improve with about 25% by 2041-2050 and with almost 388% by 2071-2080.
- The birds index is expected to improve with almost 7% in 2041-2050 and with 41% by 2071-2080.
- The collapse risk is expected to decrease with 17% in the period 2041-2050 and with almost

88% in the period 2071-2080. Nonetheless, a tentative collapse is expected to have a temporal effect on the number of expected tourists, which is expected to recover after the restoration work.

Under the scenario "**Divided road**" any effort to restore the ecosystem remains only on paper as a result of which the wetland collapses with permanent and serious damage for the biodiversity in the region. Automatically, this also impacts the fishing industry. The tourism sector, however, does not seem to experience much impact as it mainly relies on 3S-mass tourism. When compared to the 2011-2020 average annual value, we notice the following:

- The Mean Annual Salinity is expected to increase with 74% in the period 2041-2050 and with almost 164% during the period 2071-2080.
- The fish catch is expected to decrease with about 97% by the years 2041-2050 and with almost 100% in the period 2071-2080. A collapse of the lagoon system will therefore terminate any fishing activities in the region.
- The vegetation index is expected to decrease with 100% in 2041-2050 and remain the same during the rest of the period.
- The birds index is expected to increase with almost 40% in the years 2041-2050, and by 43,2% in 2071-2080.
- The collapse risk is expected to reach a maximum value by 2030.

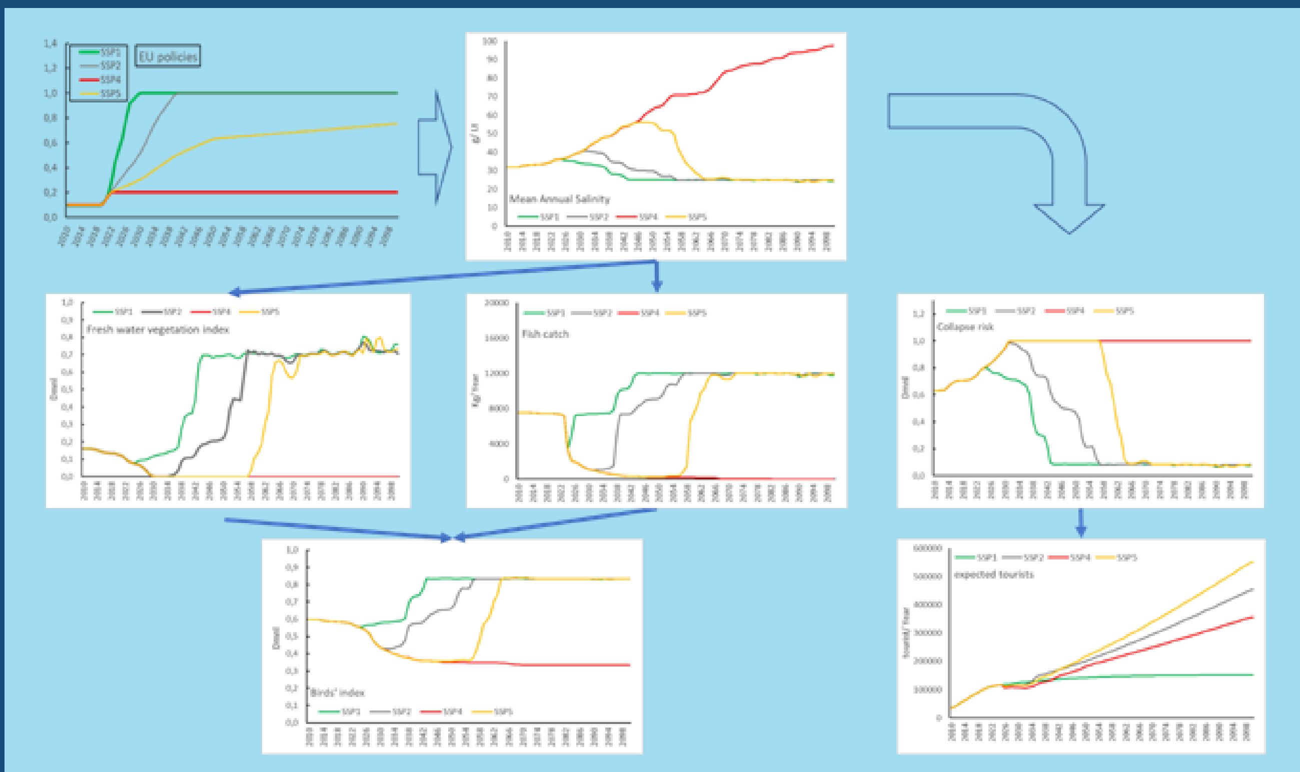

Figure 7: *SD model results for KPIs linked to wetland restoration in South-west Messinia.*

Under the scenario “**Rapid development**” a collapse of the lagoon system cannot be avoided anymore due to prolonged delays in the implementation of actions for wetland restoration. It should be possible to overcome the implications for biodiversity, fishing and tourism. Though this will take many years. When compared to the 2011-2020 average annual value, we notice the following:

- The Mean Annual Salinity is expected to increase with 68% in the period 2041-2050 and to decrease with almost 24% in the period 2071-2080 after thorough restoration works.
- The fish catch is expected to decrease with 96% by the years 2041-2050. After the restoration works, however, this value is expected to increase again with 60% by the years 2071-2080. For a long period of time fishing won’t be possible, but the activity is expected to recover in the longer term.
- The vegetation index is expected to decrease with 100% by the years 2041-2050. After the restoration works, this value is expected to increase with almost 380% in the period 2071-2080, as the availability of fresh water will again create favourable conditions for the local fauna and flora.
- The birds index is expected to increase with 39% in the period 2041-2050. After the restoration works, this value is expected to increase with 41% by the years 2071-2080.
- The collapse risk is expected to reach a maximum value already by 2030. After restoration, this value is expected to decrease with almost 88% during the years 2071-2080.

Apart from the implementation of certain policies, wetland restoration is also affected by the availability of fresh water resources. Of special focus is the groundwater aquifer of Tyflomitis, which is partly used for the water supply of the municipality (30%). Besides this, it is also used for irrigation by the local farmers (30% of catchment farmers). For as long as the abstracted volumes do not affect the stock of the aquifer (6,500,000 m^3), most of the remaining water volume is discharged as surface water (springs), which where once feeding the wetland.

The compilation of graphs in Figure 8 below, illustrates how the increase in groundwater abstractions could impact the groundwater stocks and reduce the water availability for wetland restoration.

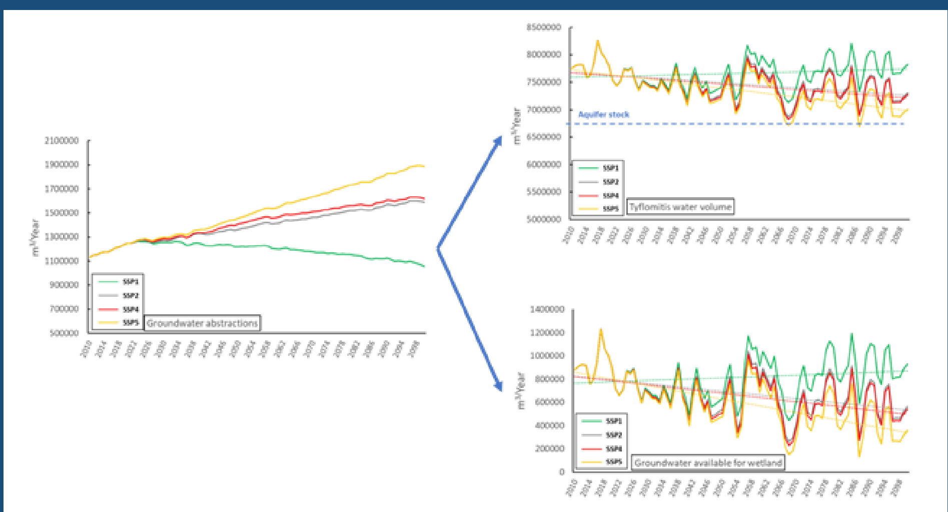

***Figure 8**: SD model results for KPIs linked to groundwater availability in South-west Messinia.*

Due to climate change (RCP 2.6), the availability of fresh water is expected to decrease. In the context of restoration actions, however, it is important to understand how much water can be available for wetland restoration under each of the scenarios. As illustrated in Figure 8, the long-term average of water availability for wetland restoration under the scenario "**Green, integrated road**" is 817,159 m^3/year, which is 18% higher than under the scenario "**Unorganized, middle road**", 21% higher than under the scenario "**Divided road**" and 31% higher when compared to the scenario "**Rapid development**".

Under the first scenario, namely "**Green, integrated road**", groundwater abstractions are expected to increase with 3% by the years 2041-2050. Though they will decrease again with 2% by the years 2071-2080, as people start to use less water in their everyday life. Because of this evolution, the groundwater aquifer remains in a good state, which results in an adequate water volume for wetland restoration. When compared to the 2011-2020 average annual value, we see the following:

- The groundwater stock is expected to decrease with 5% by the years 2041-2050 and with 1% during the second half of the century (2071-2080).
- The amount of groundwater available for the wetlands is expected to decrease with 30% by 2041-2050, which if further toned down to 6% in the years 2071-2080.

Under the scenario "**Unorganized, middle road**" groundwater abstractions are expected to increase in volume with 13% by the years 2041-2050 and with 25% during the second half of the century (2071-2080), which increases the risk of affecting the permanent stock of the aquifer. When compared to the 2011-2020 average annual value, we observe the following:

- The groundwater stock is expected to decrease with 7% in the period 2041-2050 and with 5% during the period 2071-2080.
- The groundwater available for the wetland is expected to decrease with 39% by the middle of the century (2041-2050) and with almost 30% during the years 2071-2080.

Under the scenario "**Divided road**" the groundwater abstractions are expected to increase with 15% during the period 2041-2050, and to even increase with almost 29% during the second half of the century (2071-2080). This increases the risk of affecting the permanent stock of the aquifer substantially. When compared to the 2011-2020 average annual value, we observe the following:

- The groundwater stock is expected to decrease with 7% during the years 2041-2050 and with almost 6% during the following period (2071-2080).
- The groundwater available for the wetland is expected to decrease with 40% during the period 2041-2050 and with almost 33% during the years 2071-2080.

Under the scenario "**Rapid development**" groundwater abstractions are expected to increase with 18% during the years 2041-2050 and with almost 42% in the years 2071-2080 - again increasing the risk of affecting the permanent stock of the aquifer. When compared to the 2011-2020 average annual value, we observe the following:

- The groundwater stock is expected to decrease with 7% in the period 2041-2050 and with almost 8% during the period 2071-2080. The risk to permanently damage the aquifer stock is very high.
- The groundwater available for the wetland is expected to decrease with 40% in the years 2041-2050 and with almost 33% during the period 2071-2080.

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