A comprehensive set of normative (policy) and exploratory scenarios for the case studies

MOSAIC

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Table of Contents

List of Figures

List of Tables

Abbreviations

AFTs	Agent Functional Types
BAU	Business As Usual
CCDR-Alentejo	Alentejo Regional Coordination and Development Commission
CHELSA	Climatologies at high resolution for the earth's land surface areas
CMIP6	Coupled Model Intercomparison Project Phase 6
CRAFTY	Competition for Resources between Agent Functional Types
EGO	Environment for Geoprocessing Objects
EI	Ecological Infrastructure
ELO	European Landowners' Organization
ENPLC	European Network for Private Land Conservation
ES	Ecosystem Services
EUROSITE	Network for Europe's natural site managers
GBF	Global Biodiversity Framework
GHG	Greenhouse gases
GIS	Geographic Information System
iLUC	indirect Land-Use Change
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
LPJ-GUESS	Lund-Potsdam-Jena General Ecosystem Simulator
LUC	Land-Use Change
NCCS	National Centre for Climate Services
NFF	Nature Future's Framework
PCR-GLOBWB	PCRaster Global Water Balance
PLC	Private Land Conservation
PLUM	Projective Land-Use Model
PNEC	National Energy and Climate Plan
PROT	Regional Territorial Planning Program
RCPs	Representative Concentration Pathways
RNA2100	National Roadmap for Adaptation 2100
RNC2050	Roadmap for Carbon Neutrality 2050
ScenarioMIP	Scenario Model Intercomparison Project
SDG	Sustainable Development Goals
SIMPLE-G	Simplified International Model of Agricultural Prices, Land Use and the Environment on Grid
SNAC	National System of Classified Areas
SSPs	Shared Socioeconomic Pathways
SWF	Small Woody Features
WFD	Water Framework Directive

Introduction

About MOSAIC

For many decades already, the scientific community warns about the detrimental impact of current land-use practices on biodiversity, soil fertility, water reserves, climate change, to name a few, eroding the safe operating space for humanity on Earth (Richardson et al., 2023; Rockström et al., 2009). Yet, despite the piles of reports with irrefutable evidence, not much change can be seen on the ground. Facts, figures and scenarios of the future we are heading for appear not to be enough to convince land-use decision makers to make more sustainable choices.

MOSAIC therefore wants to contribute to a better understanding of why this is the case, and, more importantly, contribute to the solutions. To that effect MOSAIC investigates the drivers behind land-use choices. Are farmers, business managers, nature conservationists, policy makers and other land-use decision makers aware of what is at stake? And what role can they play in finding a solution? What kind of land use do they favour and why? What motivates them to go for their choice? How can their decisions be aligned or reconciled with policy targets in the fields of climate change mitigation and adaptation, biodiversity and renewable energy? What tools and incentives can help to align these individual land-use decisions on the ground with high-level policy targets and international agreements aimed at the conservation of our common home?

To investigate these questions, six Policy Labs, comprising a diverse array of decision makers in Belgium, Denmark, Hungary, Portugal, Switzerland, and a European Lab, are set up as pivotal platforms for MOSAIC's transdisciplinary research. Each one is linked to a specific case of land-use decision making. These Policy Labs help the researchers investigate these questions and allow practitioners to co-create relevant knowledge, so the gained knowledge becomes truly actionable for them.

MOSAIC's modelers will build upon this knowledge about drivers and motivations to characterize expected future land-use patterns – an indispensable tool in land-use policy processes. Based on spatial, social and economic insights, potential displacement effects can be made visible, as well as evolutions jeopardizing European biodiversity, climate and renewable energy goals.

To enable this, the Policy Labs receive support from a digital learning environment in which MOSAIC bridges the siloes of researchers' and practitioners' worlds. During the project, this environment allows for knowledge transfer, learning, evaluation and collaboration between researchers and practitioners, both within the cases and in cross-case settings. After the project, this learning environment will live on to give answers to the research questions outlined above, questions about the practical implementation of these learnings; and will it function as a source of inspiration for those wanting to render land use more sustainable in other places as well.

This way, MOSAIC will showcase in six cases how policy, science and society can work hand-in-hand on concrete solutions to accelerate the transition towards more sustainable land use.

About this report

MOSAIC aims to characterise future, expected land-use patterns across its six case studies through an interregional, multi-scalar, and multi-methodological approach that investigates the behavioural and structural drivers underpinning land-use decisions. As part of Work Package 4 (WP4), this effort supports the development of robust, cross-sectoral policy goals by co-creating a comprehensive set of normative (policy) and exploratory scenarios[1] in collaboration with local stakeholders.

This report represents Deliverable 4.1, titled *"A comprehensive set of normative (policy) and exploratory scenarios for the case studies*" (Figure 1). The report outlines the participatory and methodological process undertaken to develop scenario inputs, and describes how scenario narratives and land-use models interconnect across spatial scales to support integrated land system analysis within MOSAIC.

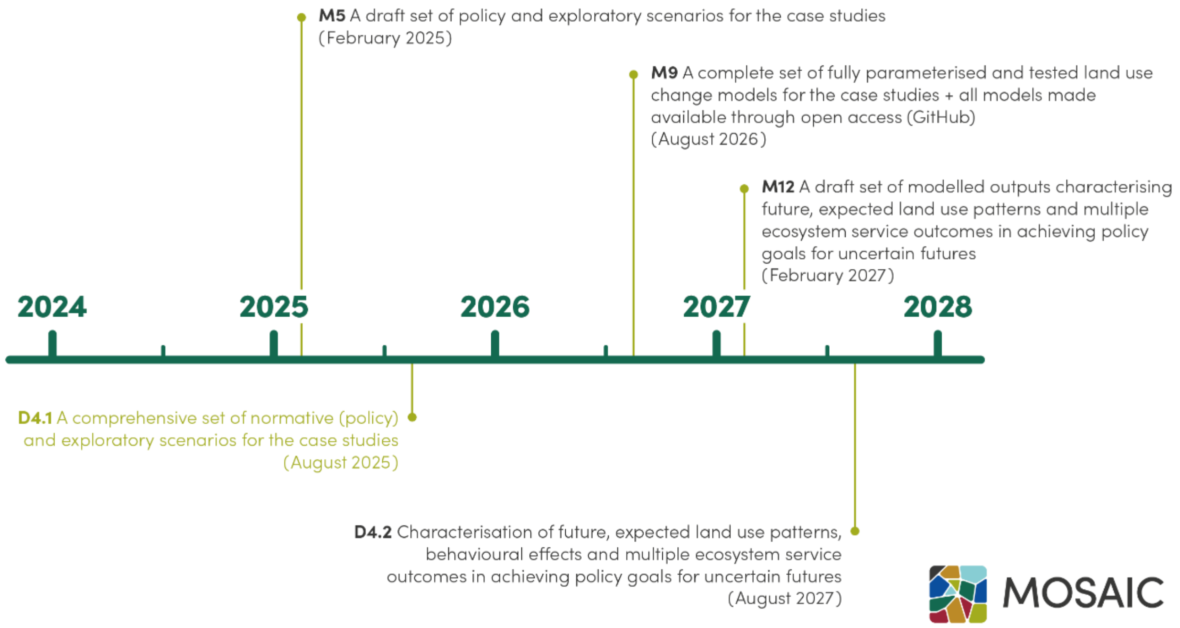


Figure 1. Timeline for Milestones and Deliverables of WP4 in MOSAIC.

The six case studies serve as the foundation for interregional learning and scenario development, with land-use models tailored to the specific socio-environmental contexts and research needs of each region. These models differ in their spatial resolution, modelling frameworks, and thematic foci, but are aligned through a common, multi-scale scenario framework designed to enable information flow and integration across spatial scales.

While the Danish (UCPH) and Swiss (ETH) case studies are formally not contributors to Task 4.1 titled "D*evelopment of future scenarios*", they feature in this report, partly with contributions from earlier work, which allows MOSAIC to adopt a combined normative and exploratory scenario approach for all cases. This will then feed into Tasks 4.2 entitled "*Model set-up,*

[1] Representations of possible futures for one or more components of a system, particularly for drivers of change in nature and nature's benefits, including alternative policy or management options (IPBES, 2023).

parameterization and testing" and Task 4.3 entitled "*Model application and analysis of results in terms of policy objectives*", which form the basis for the final modelling deliverable D4.2 titled "C*haracterisation of future, expected land-use patterns, behavioural effects and multiple ecosystem outcomes in achieving policy goals for uncertain futures*". Both Task 4.1 and Task 4.2 thus serve as a foundation to the final modelling work in Task 4.3. The final deliverable D4.2 will then allow to evaluate the success in achieving policy objectives across policy sectors that are robust to alternative socio-economic and climate change contexts and biodiversity value perspectives while highlighting trade-offs and co-benefits.

Chapter 1 provides an overview of the general scenario applied in MOSAIC, combining both exploratory and target-seeking scenarios. In chapter 2, the six MOSAIC case studies are treated. It provides their general context, modelling methods, the scenarios used, and the participatory approach taken to define them. Chapter 3 discusses the outcomes and some commonalities in scenario development across the case studies.

1 General multi-scale scenario approach

MOSAIC aims at providing solution-focused, actionable knowledge to sustainable land-use practices in line with climate mitigation, adaptation, biodiversity conservation and renewable energy objectives. This requires land-use models to investigate potential future impacts of changes across scales on nature, ecosystem services, and a good quality of life. Thus, MOSAIC applies a range of models at different spatial and temporal scales, tailored to investigate questions of local and global relevance by different modelling teams for different European cases.

Scenarios are relevant for land-use models as they provide alternative pathways[2] to possible futures, including drivers of change such as policy or management options (IPBES, 2023). The different models applied to the MOSAIC cases will follow similar main scenario assumptions, including drivers, allowing higher scale models to provide quantitative inputs, including boundary conditions where applicable, to lower scale models. Based on the categorisation by Zurek & Henrichs (2007), MOSAIC's scenario linkage across scales thus navigates between consistent and coherent scenarios (Figure 2).

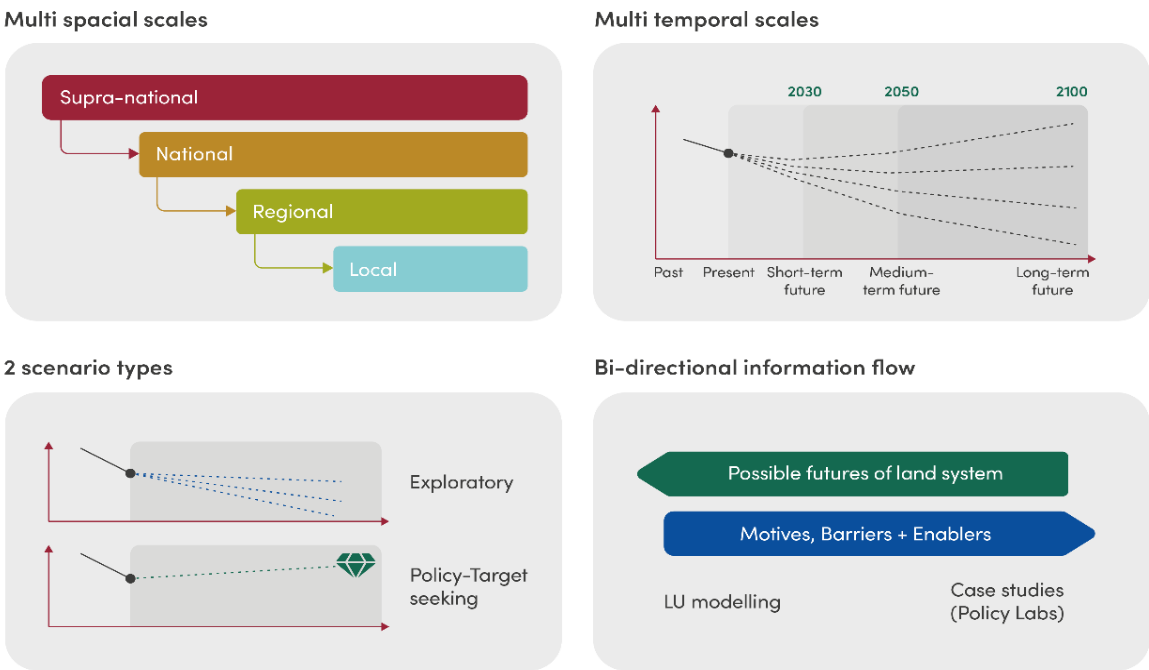


Figure 2. Multi-scale scenario approach in MOSAIC that is used across all modelling case studies involving a) land-use models at different spatial scales, arrows indicate possible inputs provided by higher scale models, b) some agreed time steps for model outputs, c) combination of exploratory and (normative) target-seeking scenarios based on policy objectives, and d) exchange of information between land-use modelling and case studies, enabled by participatory stakeholder engagement.

[2] Different strategies for moving from the current situation that lead towards a desired future vision or specified targets, thus forming a component of a scenario. These are a set of actions that build on each other, from short-term actions into broader transformation (IPBES, 2023).

1.1 Exploratory scenarios

In MOSAIC, exploratory scenarios provide insights into future land-use patterns emerging under diverging socio-economic trajectories. In this way, they provide a set of alternative baselines against which policy scenarios can be compared.

The exploratory scenarios used in MOSAIC are based on combinations of climate change scenarios through the Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011) and socio-economic change scenarios through the Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2014). RCPs represent the degree of climate change in terms of radiative forcing, with RCP4.5 referring to 4,5W/m² radiative forcing in 2100. SSPs describe different socio-economic development trajectories for society (Table 1).

Table 1. Description of the five SSPs based on O`Neill et al. (2014).

SSP1	Sustainability	The sustainable and "green" pathway describes an increasingly sustainable world. Global commons are being preserved; the limits of nature are being respected. The focus is more on human well-being than on economic growth. Income inequalities between states and within states are being reduced. Consumption is oriented towards minimizing material resource and energy usage.
SSP2	Middle of the road	The "Middle of the road" or medium pathway extrapolates the past and current global development into the future. Income trends in different countries are diverging significantly. There is a certain cooperation between states, but it is barely expanded. Global population growth is moderate, levelling off in the second half of the century. Environmental systems are facing a certain degradation.
SSP3	Regional rivalry	Regional rivalry. A revival of nationalism and regional conflicts pushes global issues into the background. Policies increasingly focus on questions of national and regional security. Investments in education and technological development are decreasing. Inequality is rising. Some regions suffer drastic environmental damage.
SSP4	Inequality	Inequality. The chasm between globally cooperating developed societies and those stalling at a lower developmental stage with low income and a low level of education is widening. Environmental policies are successful in tackling local problems in some regions, but not in others.
SSP5	Fossil fuel development	Fossil-fuelled development. Global markets are increasingly integrated, leading to innovations and technological progress. The social and economic development, however, is based on an intensified exploitation of fossil fuel resources with a high percentage of coal and an energy-intensive lifestyle worldwide. The world economy is growing and local environmental problems such as air pollution are being tackled successfully.

The global RCP and SSP scenarios have become an international standard for environmental change assessment, but more recently they have been used as a starting point for scenario development at lower spatial scales (Kok et al., 2019). Modelling groups in MOSAIC draw from existing downscaled versions of the four SSPs/RCPs combinations representing a combination of a certain degree of climate change and a development path for the world (Figure 3) where applicable or perform downscaling of higher level SSP/RCP combinations in cases where existing scenarios are unavailable. The MOSAIC modelling teams focus on SSPs/RCPs combinations of the high-priority scenarios used for the Sixth Assessment report by the IPCC, which is the group of four "Tier 1", i.e., high priority scenarios highlighted in the Scenario Model Intercomparison Project (O'Neill et al., 2016). Modelling of additional SSPs/RCPs scenarios will depend on case-specific requirements.

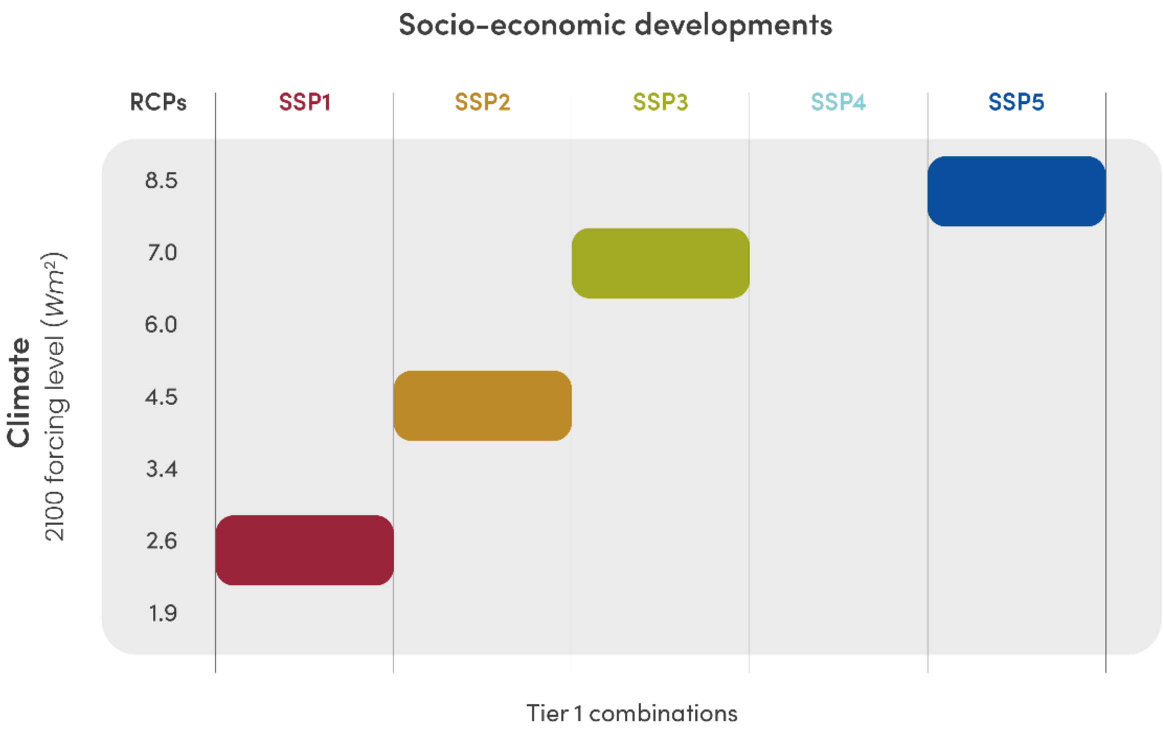


Figure 3. The four "Tier 1" combinations agreed by modelling groups of MOSAIC, adapted from O'Neill et al., (2016).

1.2 Target-seeking scenarios

Predicting policy outcomes is inherently uncertain, making it challenging for policymakers to achieve objectives related to biodiversity, climate change, and renewable energy transformation. Thus, the MOSAIC scenario approach combines exploratory scenarios as described in Section 1.1 with target-seeking scenarios. Target-seeking scenarios define clear objectives that can either be an achievable target (e.g., extent of natural habitats remaining) or a mechanism to be improved (e.g., minimal biodiversity loss) and are frequently also referred to as normative scenarios as they illustrate a desirable development. Target-seeking scenarios can contribute particularly to policy design and implementation and are useful for examining viability and effectiveness of alternative pathways towards a desired outcome. MOSAIC aims to provide policy relevant, target-seeking scenarios of the land system by incorporating current and emerging policy objectives as targets to be achieved, as well as describe their respective implementation pathways.

1.2.1 Applying the Nature Futures Framework (NFF) in MOSAIC

How current EU policy objectives will be implemented throughout Europe depends on the values that underpin societies' relationship with nature. Using the Nature Future's Framework (NFF), a flexible tool for the development of normative scenarios and models of desirable futures for people, nature and Mother Earth, scenario narratives were developed that describe the land-related actions and measures for achieving policy objectives under different value perspectives on human-nature relationships.

The NFF was developed in response to the recommendations in the IPBES Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services (IPBES, 2016). The framework can help to identify and inform context-specific policy options that contribute to the conservation of nature and a good quality of life (IPBES, 2023). Based on the diverse relationships that people can have with nature, the NFF allows to develop possible future scenarios with nature and natures' contributions to people in the centre of the process (Pereira et al., 2020). The value perspectives of the NFF can be illustrated in a triangle (Figure 4), including Nature for Nature (intrinsic value[3]), Nature for Society (instrumental value[4]), and Nature as Culture (relational values[5]). While the corners of the triangle represent extreme cases of a specific value perspective, the space between the corners is a continuum and provides the opportunity for various combinations between the value perspectives.

Using the NFF, several modelling groups within MOSAIC have developed target-seeking scenario narratives that describe the land-related actions and measures required to achieve policy objectives under the three value perspectives. These scenario narratives enable a more nuanced exploration of how future land use could evolve in response to case-relevant policy interventions, technological advancements, and socio-economic transformations. The scenario narratives for the European case (Section 2.1.4) were offered to the regional cases to be adapted to their contexts. Consequently, the scenarios can be used in modelling to

[3] The value of nature, ecosystems, or life as an ends in themselves, irrespective of their utility to humans (Arias-Arévalo et al., 2017; Pascual et al., 2017).

[4] The value of an entity as merely a means to an end (Arias-Arévalo et al., 2017; Pascual et al., 2017).

[5] The importance attributed to meaningful relations and responsibilities between humans and between humans and nature (Arias-Arévalo et al., 2017; Pascual et al., 2017).

characterise the consequences of current EU and regional policy objectives on future land use (see Deliverable 4.2).

Figure 4. The value perspectives of the NFF illustrated in a triangular space. Corners of the NFF illustrate extreme cases of the value perspectives (Schmitt et al., 2025; drawing by Anke Dregnat and Manuel Recker).

1.3 Participatory stakeholder approach

Stakeholder involvement is used to ensure that the scenario outcomes align with the policy intentions of the individual MOSAIC Policy Labs. This includes the identification of emerging policy targets by relevant stakeholders. Additionally, target-seeking scenarios based on reviewed policy documents are evaluated by stakeholders to identify conflicts in policy objectives and potential solutions to mitigate these.

1.4 Combining target-seeking and exploratory scenarios

Target-seeking scenario narratives are used in a 'stress-testing' approach under a range of SSPs/RCPs combinations, or business-as-usual (BAU) scenarios. Stress testing means to assess the capacity of normative scenarios to remain robust under different future socio-economic and climate conditions. First, policy targets relevant to the cases, identified through document analysis and stakeholder interactions, are defined. On the one side, the policy targets can be investigated with the case-specific models using a range of SSPs/RCPs scenario combinations to identify potential land-use scenario outputs. On the other side, the policy targets can also be used to define NFF-based pathway narratives which are then simulated in the respective models (Figure 5). This provides a way of evaluating the capacity to achieve the policy objectives under a range of alternative socio-economic and climate change trajectories (see Deliverable 4.2).

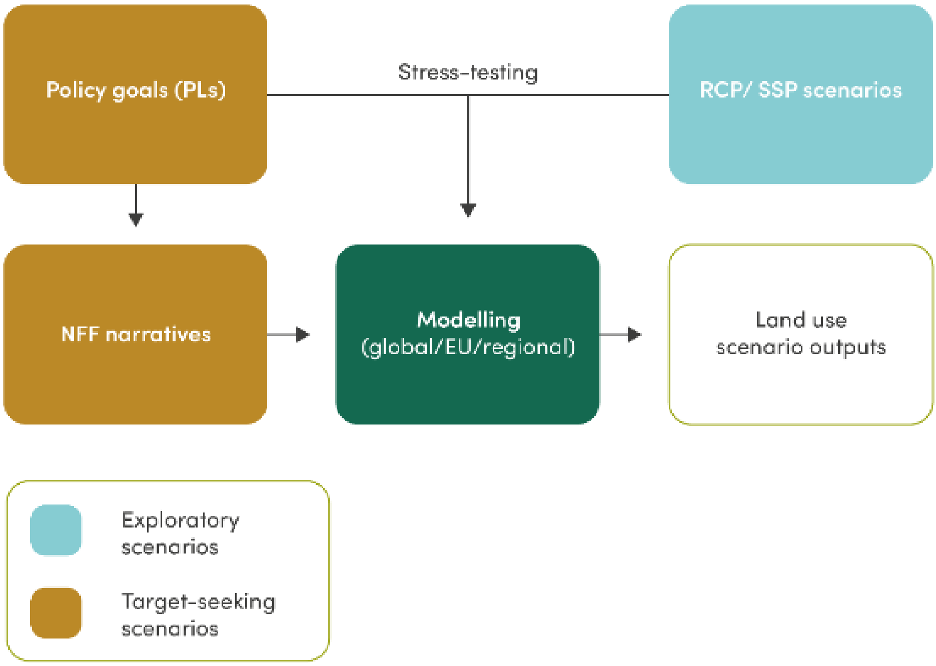


Figure 5. Interactions of exploratory and target-seeking scenarios in MOSAIC to facilitate stress-testing of target-seeking policy implementations under varying socio-economic and climatic trajectories.

2 MOSAIC case studies

This section presents the development and outcome of future scenarios across each of the six MOSAIC case studies, including the interactions with stakeholders of each Policy Lab to derive case-specific inputs for the creation of normative policy scenarios. A summary of models and scenarios used within each MOSAIC case is provided in Table 2.

Table 2. Land-use models and scenarios used across MOSAIC case studies.

Case study	Model	Spatial scale	Temporal scale	Scenarios
Europe	CRAFTY-Europe, agent-based model	Supra-national; EU27+UK, Switzerland and Norway; 1km resolution	Now-2100, annual intervals	Exploratory scenarios: Tier1 SSPs/RCPs +SSP4/RCP4.5; Target-seeking: NFF-based pathways to achieve EU policy objectives
Belgium	GeoDynamix (RuimteModel Vlaanderen), Activity-based Cellular Automata model	National to local; Flanders (Belgium); 100m resolution	Now-2100, annual intervals	Exploratory scenarios: Tier1 SSPs/RCPs; Target-seeking: single normative perspective (mostly representing Nature for Society) pathway towards EU, Flemish and local policy objectives
Denmark (not formally part of D4.1)	TargetEcon, Spatially Explicit environmental economic optimisation model	National; approx. 1 mio decision units (polygons)	Now to 2030 & Now to 2050	Exploratory scenarios: SSP1, SSP2, SSP3; Target-seeking: NFF-based pathways towards the Danish tripartite agreement targets
Hungary	CRAFTY-Europe, agent-based model	National, 1km resolution	Now-2100, annual intervals	Exploratory scenarios: Tier1 SSPs/RCPs; Target-seeking: NFF-based pathways towards nature-positive land use in the Sand Ridge region.

Portugal	CRAFTY-PT; agent-based model	Regional, 1km resolution	Now- 2100 annual intervals,	Exploratory scenarios: Tier 1 SSPs/RCPs; Target-seeking: NFF-based pathways towards a balanced nature-positive regional development
Switzerland (not formally part of D4.1)	Dinamica EGO in conjunction with ForClim and PCR-GLOBWB; Pattern-based LUC model	National; Switzerland; 100m resolution; focus on Alps	Now-2100, decadal steps	Exploratory scenarios: Tier 1 SSPs/RCPs Target-seeking: NFF-based pathways towards restoration targets in Swiss Alps

2.1 Europe

2.1.1 General context

The European case aims to explore how policy decisions and other behavioural drivers influence land-use change throughout Europe (EU, Switzerland, Norway, UK). To ensure that scenarios to be modelled are relevant to stakeholders, the European case has established a Policy Lab consisting of the European Landowners' Organization (ELO) and the network for Europe's natural site managers (EUROSITE). The policy lab convenes landowners, conservationists, and other stakeholders to examine private land conservation (PLC) issues in light of key EU policy targets. PLC is not only considered as strictly private land, but also includes community-owned land, but distinct from government-owned land. The European case further conducts analyses to understand how past policies and other behavioural drivers have impacted land-use transitions, which are being investigated in WP3 of the project and then employs EU-wide modelling to anticipate the effects of current and emerging policies, which is the subject of subsequent tasks in this WP where the models will be set up, parametrized, tested and finally applied to evaluate policies.

2.1.2 Modelling methods

The modelling in the European case will be based on a large-scale agent-based land-use model, CRAFTY-Europe. CRAFTY-Europe is designed to allow efficient but powerful simulations of a wide range of land uses across large geographical extents, based on the decision making of simulated land managers who generate a variety of ecosystem services (Brown et al., 2019). CRAFTY is part of the Land System Modular Model (LandSyMM) and coupled to a global socio-economic land-use model that provides national demands for land-based production (PLUMv2) (Alexander et al., 2018) and a dynamic global vegetation model (LPJ-GUESS) (Smith et al., 2014) (Figure 6). In turn, the European model's outputs (e.g., land-use transitions, ecosystem services) serve as boundary conditions for more localized or regional models used in other MOSAIC case studies. CRAFTY-Europe simulates land-use change at 1km^2 resolution and is updated with a new module that can simulate behavioural characteristics of land managers, such as attitudes towards intensification or the influence of social networks. The model will be useful to simulate the implementation of the developed scenarios, including different pathways to implement EU policies.

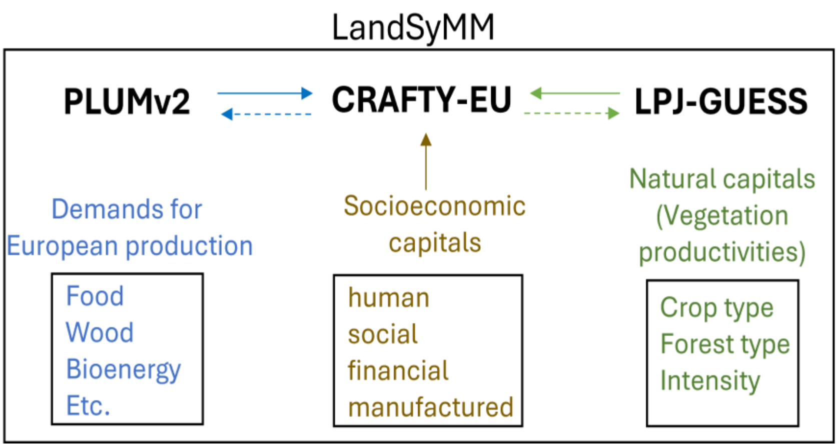


Figure 6. Simplified graphical representation of the information flow between models within the LandSyMM framework, and scenario specific inputs to CRAFTY. LPJ-GUESS provides data on the

global forest state and potential European forest and cropland productivity to PLUMv2 and CRAFTY. PLUMv2 calculates global land use and food trade and CRAFTY simulates spatially explicit European land use and supply based on demands provided by PLUMv2. Based on the land use calculated by CRAFTY and PLUMv2, LPJ-GUESS simulates the structure and carbon cycle of European ecosystems in detail.

2.1.3 Exploratory scenarios

KIT generates exploratory scenarios as input into the agent-based model CRAFTY-Europe to characterise future land-use change on a European scale (Brown et al., 2019). This European-scale scenario framing is then used to inform regional and local land-use models across the MOSAIC case studies. For the European case, the four "Tier 1" SSPs/RCPs combinations will be modelled. SSP4/RCP4.5 will be additionally modelled to allow comparison to SSP2/RCP4.5 and will explore the effect of increased global inequality but somewhat successful cooperation within Europe (SSP4), for a moderate emissions-reduction pathway (RCP4.5).

Table 3. Scenario matrix describing socioeconomic and dietary assumptions in LandSymm.

Scenario	Socioeconomic narrative	Dietary narrative
SSP1-RCP2.6	A shift towards sustainability characterised by a focus on environmental protection, investment in education, health, and international cooperation. Reduced consumption leads to reduced pressure on the environment and lower GHG emissions. Population growth is low. High economic growth results in a rapid increase in average incomes.	Rapid reduction in the consumption of animal products and sugar, and an increase in the consumption of pulses and oil crops. All countries converge towards a healthier, more sustainable diet as incomes increase. Dietary preferences shift 100% towards the EAT Lancet diet[6] by 2050.
SSP2-RCP4.5	Pathway that represents past and current global development into the future. Some level of globally concerted efforts towards environmental goals, but inequality remains high among states. Global population growth and economic growth are moderate.	Dietary preferences remain unchanged from historical patterns characterised by growing consumption of animal products, oil crops, and sugar as incomes increase.
SSP3-RCP7.0	Lack of international cooperation, regional conflict and weak global institutions lead to a lack of concerted effort in addressing environmental and societal problems. Resource use and fossil fuel intensity are high. Population growth is uneven, with higher growth in developing countries. Economic growth is sluggish and little progress is made in developing countries.	Dietary preferences remain unchanged from historical patterns characterised by growing consumption of animal products, oil crops, and sugar as incomes increase.

[6] EAT-Lancet or Planetary Health Diet from the EAT-Lancet Commission: https://eatforum.org/eat-lancet-commission/the-planetary-health-diet-and-you/

SSP4-RCP4.5	Global disparities in economic prosperity grow due to uneven investment in human capital. A shift towards sustainability and reducing GHG emissions is mostly limited to high income countries with little progress elsewhere. Population growth is low in high-income countries and high in low-income countries. There is moderate economic growth in industrialised and middle-income countries and low growth in low-income countries.	Unequal socioeconomic development leads to a partial progress towards healthier and more sustainable diets. Dietary preferences shift 50% towards the EAT Lancet diet by 2050.
SSP5-RCP8.5	Fossil-fuel driven development results in relative prosperity and rapid development globally. The focus on economic growth means that global environmental issues are neglected and GHG emissions are high. Demand for commodities is high due to rapid economic growth. Population growth is low and rapid economic growth leads to a very high global average income.	Dietary preferences remain unchanged from historical patterns characterised by growing consumption of animal products, oil crops, and sugar as incomes increase.

SSP-specific national commodity demands used in CRAFTY are provided by PLUMv2 (Alexander et al., 2018). In accordance with the SSPs/RCPs narratives of land use (Table 3), SSP1- RCP2.6 shows low overall food and wood demand based on population decline and a shift to EAT-Lancet diet, but high demand for second generation bioenergy for climate mitigation in line with RCP2.6 (Figure 7). Demands in SSP2-RCP4.5 describe a middle of the road scenario, with business-as-usual leading to increasing food and wood demand. SSP3-RCP3.70 exhibits increases in food and wood demand due to population growth in the late century and little focus on climate mitigation leads to low increases in bioenergy. SSP4-RCP4.5 follows an intermediate trend, with some dietary shifts and population decline leading to less food demand. SSP5-RCP8.0 is characterised by sharp increase in wood and food demand based on strong GDP growth and some population growth.

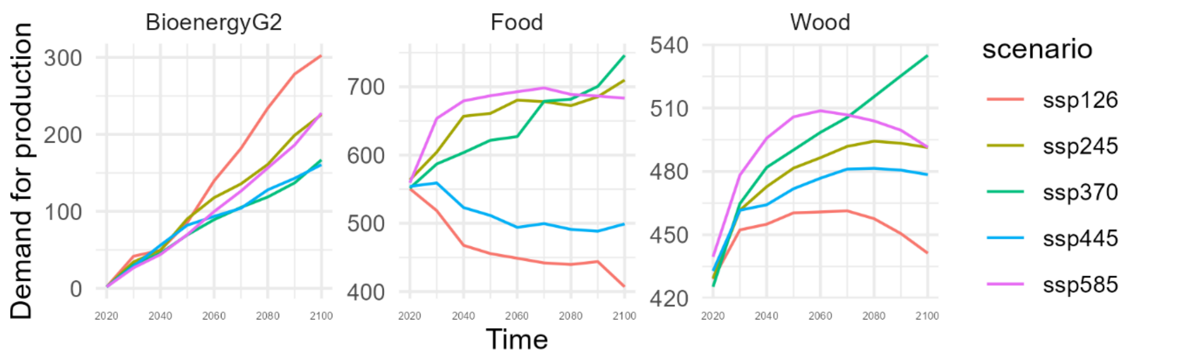


Figure 7. Examples of demands aggregated to European scale obtained from the global land-use model PLUMv2. Values are unitless. Scenarios described are ssp126=SSP1-RCP2.6; ssp245=SSP2-RCP4.5; ssp370=SSP3-RCP7.0; ssp445=SSP4-RCP4.5; and ssp585=SSP5-RCP8.5.

Socio-economic capitals can influence the productive potential within CRAFTY. These socio-economic capitals make reference to the European SSP narratives (Kok et al., 2019) and were developed to take into account a broad set of socioeconomic indicators across Europe (Raymond et al., Under Review). Using harmonised data from Eurostat and the European Social Survey, KIT produced 5 km-gridded projections of 18 indicators for all five SSPs, which are then aggregated into four types of socioeconomic capital - human, social, manufactured, and financial (Figure 8). SSP1 fosters socioeconomic convergence and high social capital, while SSP3 and SSP4 exacerbate inequality and fragmentation. SSP5 exhibits the greatest economic growth but is accompanied by steep declines in environmental protection investment, whilst SSP2 largely maintains current regional inequalities.

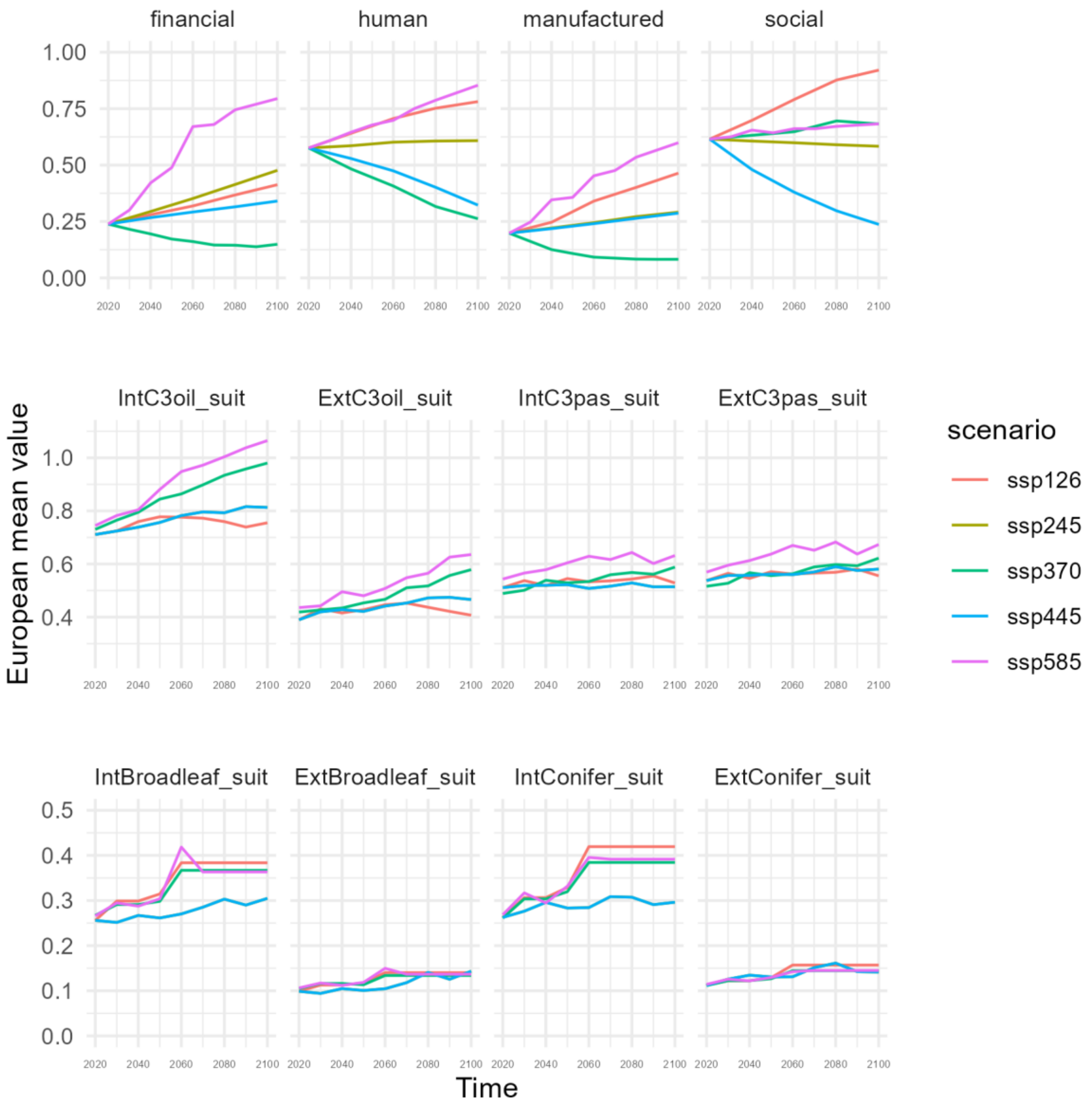


Figure 8. Examples of socio-economic (upper row) and natural (mid and lower row) capitals used in CRAFTY- Europe. Values are aggregated to a European mean. Values are unitless for socio-economic capitals, while natural capitals are expressed in optimal yield potential in dry mass per square meter and year (kgDM-m2-yr). Scenarios described are ssp126= SSP1-RCP2.6; ssp245= SSP2-RCP4.5; ssp370= SSP3-RCP7.0; ssp445= SSP4-RCP4.5; ssp585= SSP5-RCP8.5.

Additionally, vegetation productivities (natural capitals) contribute to the productive potential in CRAFTY and are provided by RCP-based projections from LPJ-GUESS (Smith et al., 2014). In Figure 8, we provide some examples on optimal vegetation productivities for crops (C3oil_suit), pasture (C3pas_suit) and wood (Broadleaf_suit and Conifer_suit) under different management categories (intensive versus extensive). Vegetation productivities of extensive crop agents are usually lower compared to intensive ones, as they are assumed to exhibit lower fertiliser usage and no irrigation. Similarly, extensive wood productivity is lower than under intensive management, as less selective removal of trees (thinning) is assumed.

2.1.4 Target-seeking scenarios

Based on a systematic review of EU policy documents (Raymond et al., In Press), both binding and non-binding EU policies that are most relevant to the land system were selected and grouped into thematic clusters (Figure 9).

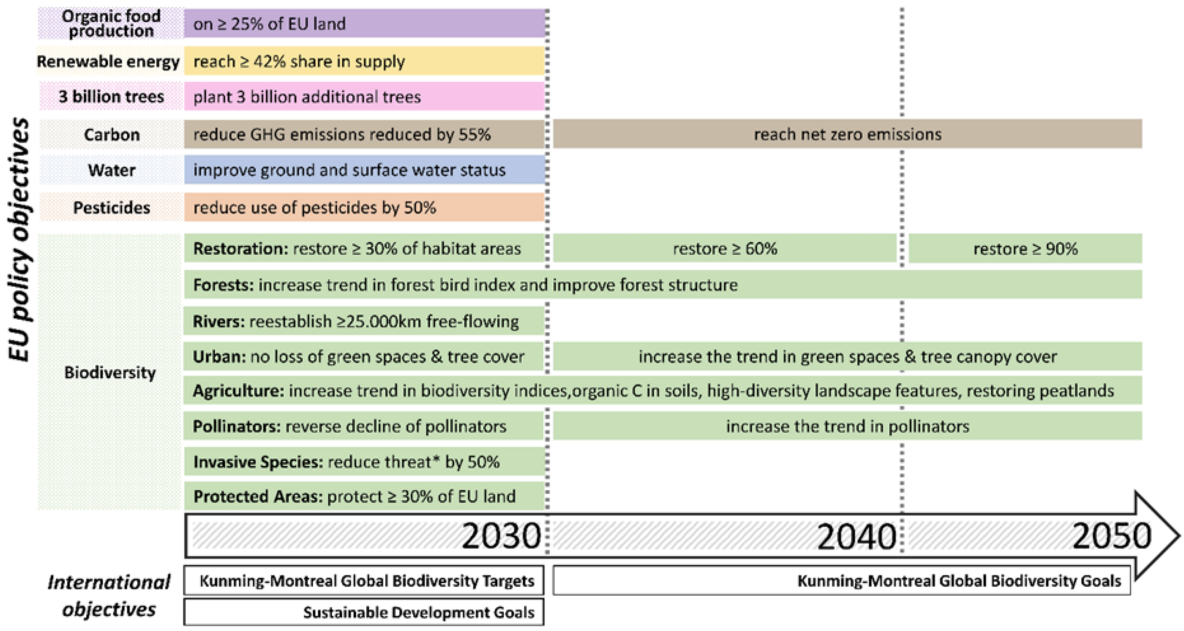


Figure 9. Overview of the timeline of identified EU Policy objectives in their thematic clusters.; KM-GBF = Kunming-Montreal Global Biodiversity Framework; SDG = Sustainable Development Goals. GHG = Greenhouse gases. * reduce the number of Red List species threatened by invasive species. The seven major thematic clusters are shown in the first column (Raymond et al., In Press).

Three pathway narratives on achieving the identified EU policies were then created, according to the distinct value perspectives described in the NFF. This was done in a two-day workshop with nine experts in ecology, geography, policy, and conservation. Participants established a shared understanding of the NFF and developed three narratives per policy objective through an inductive process to identify key elements for the implementation of policy objectives and create synthesised narratives. An overarching EU narrative was also formulated (Table 4). Afterwards, an additional group of ten reviewers assessed the narratives for coherence and alignment with NFF values (see methodological details in (Raymond et al., In Press).

Table 4. Summary interpretation of the overall pathway narratives to a nature-positive EU land system.

Pathway narratives	Landscape approach	Land management
Nature for Nature	The EU prioritises the strict protection of large areas where ecological processes are restored with minimal human management, placing emphasis on land sparing approaches.	With land being prioritised for nature, demand on land is met by land sparing approaches that sustainably intensify in high yield areas that are of least importance for biodiversity, while organic farming uses agro-ecological and plant breeding solutions to increase yields where possible. Renewable energy and land-use policies are tailored to reduce ecological impact. Restoration practices with the most effective outcome for biodiversity are prioritised.
Nature as Culture	The EU places emphasis on land sharing and multifunctional landscapes which integrate nature into all aspects of local culture.	Agriculture uses traditional, nature-positive land management practices leading to an emphasis on local solutions, as opposed to widespread technological interventions. Renewable energy and land-use policies are tailored to maintain the integrity of cultural landscapes. Restoration practices focus on restoring native and culturally important species in cultural landscapes.
Nature for Society	The EU balances the supply of ecosystem services for society with nature in multifunctional landscapes.	Sustainable intensification of the most productive land utilises upscaled technology to increase the efficiency of inputs. Organic farming methods are used where possible to provide multiple ecosystem services. Renewable energy and land-use policies incorporate technologies to increase the cost effectiveness of integrating energy sources into multifunctional landscapes. Restoration practices focus on restoring the function of ecosystems to enhance the supply of ecosystem services.

2.1.5 Participatory stakeholder approach

The MOSAIC European Policy Lab underscores the critical role of private[7] landowners in achieving the EU Biodiversity Strategy for 2030. Private Land Conservation (PLC) is highlighted as a key complement to formal protected areas, enabling conservation across productive landscapes (MOSAIC, 2025). The Policy Lab connects diverse land managers through key actors such as the European Landowners' Organization (ELO) and EUROSITE, alongside their national and regional members (Figure 10).

[7] i.e. as opposed to publicly owned, governmental land, thus including both community-owned (such as by nature conservation organisations) as privately-owned.

Figure 10. Conceptual figure on integrating private land conservation with the EU Biodiversity Strategy, developed by the EU Policy Lab (MOSAIC, 2025).

A novel workshop format was developed within the MOSAIC EU Policy Lab, encouraging stakeholders to contribute to an integrated and pluralistic pathway narrative. This narrative explicitly recognizes the diverse value orientations that private landowners hold toward conservation based on the NFF, namely prioritizing ecological protection and restoration (intrinsic values), emphasizing cultural heritage, stewardship, and personal ties to land (relational values), and focusing on economic viability and material benefits from nature (instrumental values). Participants assessed their alignment with these narratives and collaboratively identified key actions, barriers, enabling factors, and policy measures. This bottom-up, pluralistic approach ensured that resulting strategies reflect both the value diversity and the practical realities of those managing Europe's landscapes. The format was successfully piloted and refined at key events, including the ENPLC conference in Brussels (March 2024), the EUROSITE Annual Conference in Durham, UK (October 2024), and a final joint online workshop hosted by the EU Policy Lab (May 2025). This last session focused on nature restoration, generating critical insights for the development of policy-relevant and model-informed EU scenarios for land use and habitat connectivity.

In advancing the EU's target of restoring 90% of habitats by 2050 and improving landscape-level connectivity, stakeholder input revealed a clear emphasis on instrumental and relational values. While all three value perspectives were presented and explored, participants focused most on Nature as Culture and Nature for Society. This was evident in the triangle exercise, where significantly fewer participants placed themselves in the Nature for Nature corner, which indicates less emphasis on a purely eco-centric, preservationist approach.

Stakeholders emphasized practical and policy-relevant priorities such as climate-smart restoration, payments for ecosystem services, and compatibility with traditional land-use practices. They underscored the importance of ensuring profitability of nature restoration, for instance through biodiversity or carbon credits. Participants also called for greater integration of regenerative practices, cross-sector cooperation, and funding availability, consistently stressing the need for solutions to align with landowner realities. The most effective strategies are those that build synergies across value perspectives, rather than treating them as competing goals. The workshop finally revealed the following pluralistic pathway for nature restoration using private land conservation in Europe:

> *"Restoration focuses on traditionally important landscapes, such as heathlands and alpine grasslands, through the maintenance and reintroduction of traditional management practices that sustain cultural landscapes. Restoration efforts prioritizes emblematic endemic species that align with traditional land-use practices and habitats are connected through landscape modifications that link low and high biodiversity areas. In agricultural and rural landscapes, restoration supports biodiversity while not impairing material benefits. It includes climate-smart solutions that emphasize carbon storage, co-benefits from regulating services, and reducing risks to lives and assets from extreme weather events.* (Raymond et al., In Press)*"*

2.2 Belgium

2.2.1 General context

The Belgian case focuses on the Landscape Park Flemish Ardennes, a region of ca. 25.000 ha, at the border of Flanders and Wallonia. The region is characterised as a small-scale, hilly landscape with forests, open fields, and grasslands surrounded by small woody features such as hedges (so-called ‘bocage landscapes’). These small-scale grasslands are under pressure and are disappearing because of agricultural industrialization (disappearance of small-scale livestock farming), urban sprawl (farmland lost to private use), environmental objectives (afforestation), and the search for water-secure arable land (higher profitability of crops compared to grassland).

The Masterplan of the Landscape Park outlines the ambitions for the next 24 years, aiming to positively advance agriculture, nature, cultural heritage, and tourism towards a new balance. These ambitions are summarized in three systemic strategic objectives: revitalizing the landscape, restoring the interconnected landscape, and revitalizing the villages. The second strategic objective, “interconnected landscape,” forms the context in which the Belgian Policy Lab is operating. This objective involves restoring the cultural bocage landscape, where various actors—such as farmers, residents' associations, and nature managers—collaborate to manage and strengthen the landscape. Since the landscape of the Flemish Ardennes is largely managed by farmers (mainly livestock farming), who have a strong connection with grasslands, the Landscape Park aims at strengthening the opportunities for profitable, land-based farming in order to reach the strategic objective. This includes exploring new grassland revenue models for farmers—both for productive grasslands and grasslands managed for nature conservation purposes.

The goal of the Belgian policy lab is to help the Landscape Park develop such a robust, future-proof strategy for grasslands, taking into account current and future threats and opportunities.

2.2.2 Modelling methods

Land-use changes in the Flemish Ardennes will be modelled using the GeoDynamiX land-use model. GeoDynamiX is an activity-based cellular-automata model (Crols et al., 2015; White et al., 2012) that simulates future land use and activities (such as population and employment) for the whole of Flanders at a spatial resolution of 1 ha and a yearly temporal resolution.

The model is driven by demands for activity (such as population growth) and land use (such as forested area) at the regional (Flemish) level. It modifies these activities and land-use states in each 1ha cell on an annual basis by computing a potential for each activity. This potential for each land-use type consists of four elements: zoning legislation, physical suitability, accessibility to transportation networks, and the neighbourhood effect (Figure 11). While the first three elements can be represented by a set of maps, the neighbourhood effect is a distance-decay function that represents the level of attraction and repulsion effects between land uses, the population and employment at a continuous range of scales, from the cellular to the regional level. We refer to Crols (2017) for an extended technical description of the model and its background.

The current GeoDynamiX model emphasises land-use changes that appear in an urbanizing environment (Vermeiren et al., 2022). In MOSAIC, ILVO and VITO will develop a new ‘grassland module’ that should be able to better address the grassland dynamics. The development of this new grassland module is part of Task 4.2 of MOSAIC and will build on data analysis of historical time series on grassland changes, on the one hand, and on the qualitative insights of drivers of grassland change that are gathered in WP3 of MOSAIC on the other hand.

The GeoDynamiX model will be coupled to the Nature Value Explorer (Broekx et al., 2013; Liekens et al., 2023). This is an online tool that enables spatially explicit valuation of ecosystem services across Flanders. This coupling thus allows to calculate the effect of the simulated land-use changes on ecosystem functioning and the services provided for a broad range of ecosystem services that fall under all three value perspectives (intrinsic values, instrumental values and relational values) of the NFF (Table 5).

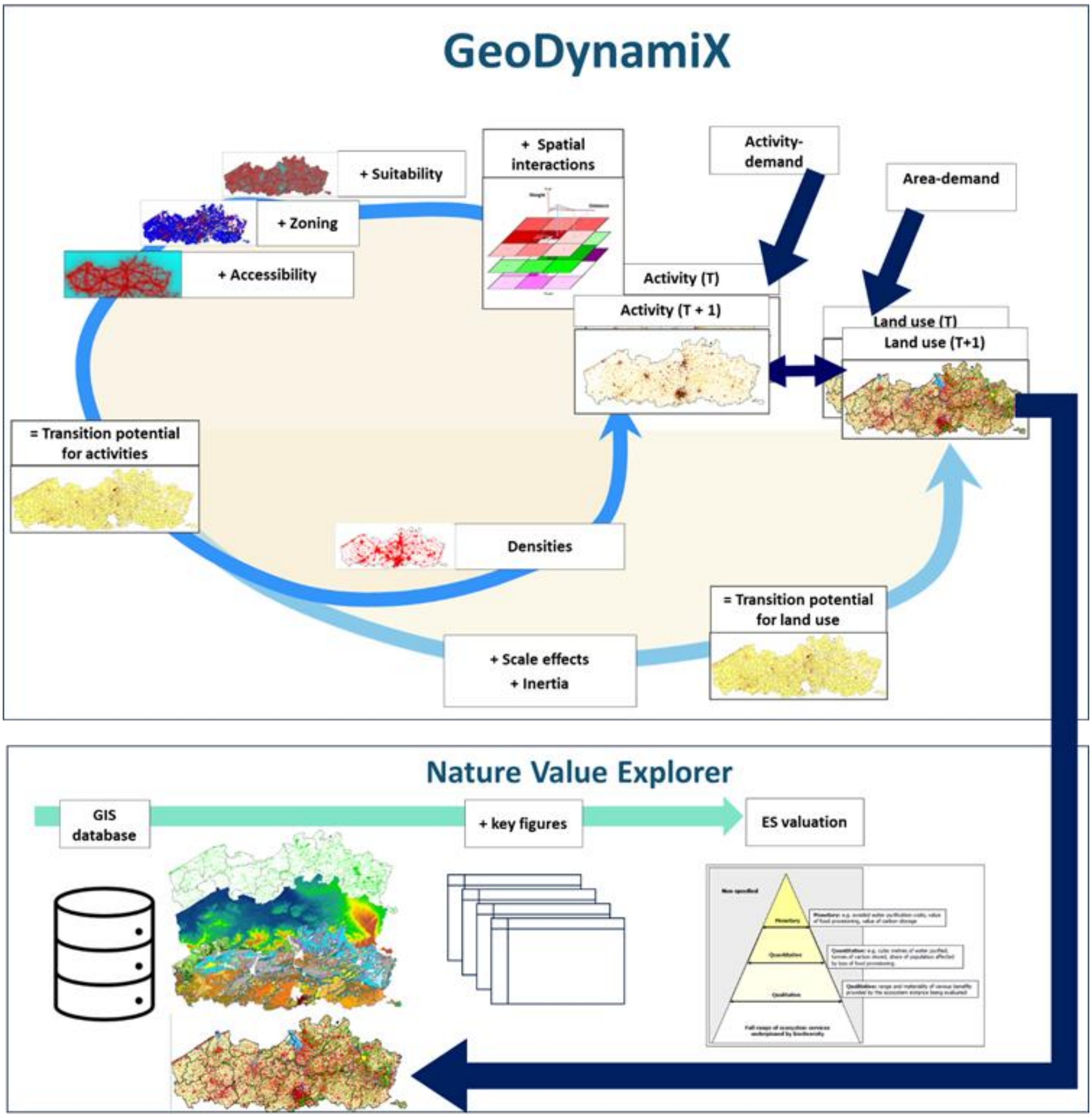


Figure 11. Illustration of the GeoDynamiX land-use model.

Table 5. Overview of ecosystem services and availability of valuation methods in the Nature Value Explorer that are relevant for the valuation of grasslands in the Flemish Ardennes

Value type	Value	Ecosystem service	Qualitative	Quantitative	Monetary
Intrinsic value of nature	Biological value		x		
Instrumental value **Provisioning services**	Food production	Agricultural crops	x	x	x
		Livestock and dairy products	x	x	x
Relational value **Regulating services**	Reducing waste, toxic substances and other nuisance	Water purification by nutrient removal	x	x	x
	Regulating water and land flows	Water infiltration/ groundwater recharge	x	x	x
		Protection against water erosion	x	x	x
	Regulating the physical, chemical and biological environment	C-storage in soil and biomass	x	x	x
		Pollination and seed dispersal	x	x	x
Relational value	Landscape attractivity		x	x	

Within the Belgian case, the GeoDynamiX model will be used both at the regional scale (Flanders) and the local scale (Flemish Ardennes Landscape Park, Figure 12).

At the regional scale, the model will be used to translate the exploratory scenarios (see section 2.2.3) to future land-use change in Flanders, using the outputs of the CRAFTY model as boundary conditions. Hereto, the 1km² results of the CRAFTY model will be aggregated to results at the Flemish level.

At the local scale, as part of the target-seeking scenarios, different pathways for grassland development in the Landscape Park Flemish Ardennes will be modelled using GeoDynamiX (see section 2.2.4).

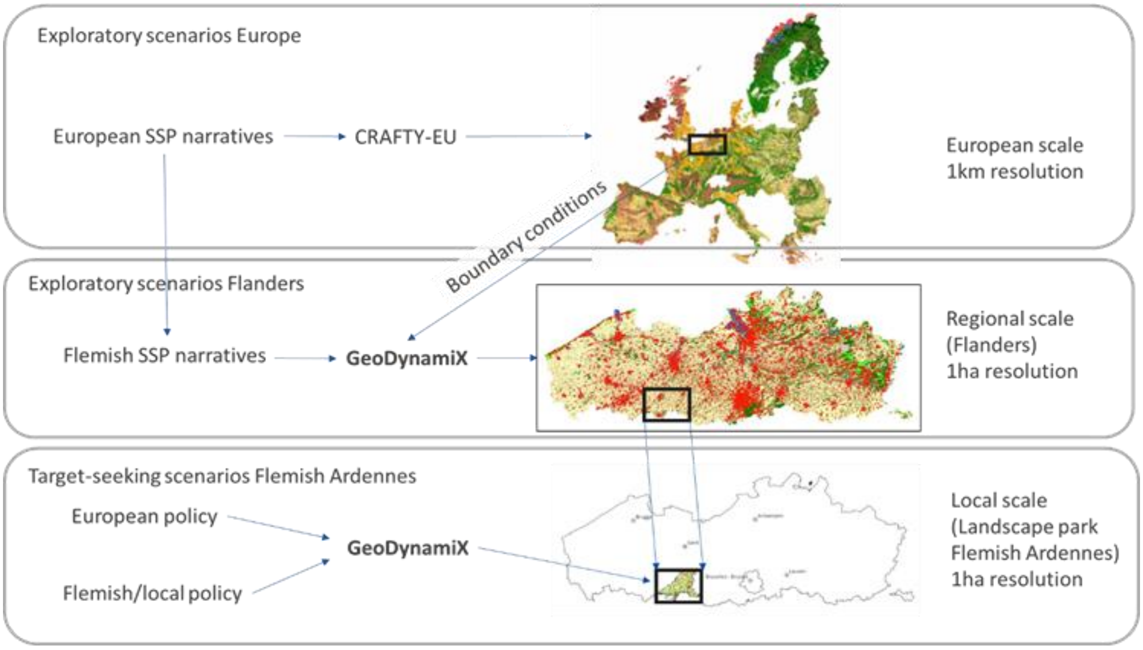


Figure 12. Simplified graphical representation of the information flow between CRAFTY-Europe and the GeoDynamiX model in the multi-scale approach for both exploratory scenarios and target-seeking scenarios.

2.2.3 Exploratory scenarios

The exploratory scenarios will build upon the exploratory scenarios that are built and modelled at the European scale (see section 2.2.5). As in the European case, the Belgian case will thus aim to explore all SSPs/RCPs Tier1 combinations.

In practice, this means that some of the input parameters for the GeoDynamiX model (e.g. regional demand) will be based on the regional outputs (aggregated to the Flemish level) of the CRAFTY model. For the parameterization of other model parameters that cannot be directly derived from CRAFTY, the European SSP scenarios will be further refined to Flanders-specific SSP scenarios.

Flanders-specific SSP narratives have previously been developed and simulated with the GeoDynamiX model in the Horizon Europe COASTAL-project (Grant Agreement No. 773782) (D'Haese, 2021). These scenarios will be further refined to be usable in the newly developed grassland module of GeoDynamiX and to better align with the scenario preferences of the stakeholders. The stakeholders consulted are mainly interested in investigating the effects of e.g. the aging of the farming population, the decrease in agricultural profits, upscaling of farming practices etc. on the grassland system in Flanders and the Flemish Ardennes (see section 2.2.5).

2.2.4 Target-seeking scenarios

Based on the inputs from the workshop participants (see section 2.2.5), a selection was made of (mainly binding, regulatory) policies at the European, Flemish and local (province of Oost-Vlaanderen) level that have an impact on grasslands (Table 6). This includes impacts on the grassland dynamics (land-use changes), as well as impacts on the functioning of grasslands (e.g., by restricting fertilization use or other management practices in certain locations). For each policy, the spatial priorities relevant for grasslands were identified. These spatial priorities will be used to parameterize the GeoDynamiX land-use model.

Based on the stakeholder consultation (see paragraph 2.2.5), it was decided to develop a single overarching narrative in which these policy goals are achieved. This overarching narrative was entitled 'Farming Despite Nature' ('Boer ondanks natuur' in Dutch) and aims to explore how the agricultural value of the remaining grasslands can be maintained or enhanced, taking into account the various (nature) objectives that play a role in the Flemish Ardennes. The title of this scenario was deliberately chosen to be provocative, intentionally and at the request of the stakeholders involved in the policy lab. Farmers play an important role in managing grasslands in the Flemish Ardennes. Nearly two thirds of the grassland area is managed by professional farmers, for whom economic viability is a key driver. A viable agricultural sector is therefore seen as essential for the protection and restoration of grasslands in the Flemish Ardennes. This does not mean, however, that the scenario's impact on other grassland values that do not directly contribute to farm income will not be studied. Within this overarching narrative, different pathways to reach the targets will be explored. These different pathways were proposed by the workshop participants and include several possible directions in which the agricultural sector could evolve, such as a shift from current conventional farming to more extensive livestock systems, the transition from family farms to agro-industrial agricultural complexes, the reduction of plots used for hobby farming, the implementation of a compartmentalized farming model, etc.

The overarching narrative appears to align most closely with the Nature for Society' scenario from the NFF framework, in which the instrumental value is considered most important. Both the masterplan, as well as the consulted stakeholders, however, mention several other grassland values as being important in the Landscape Park, such as erosion control, water retention, climate mitigation, habitat for specific grassland species, landscape experience and recreation, that align with the other NFF value perspectives Nature for Culture (relational values, such as landscape attractivity) and Nature for Nature' (intrinsic values, such as biodiversity). The modelling exercise that will be set up, will therefore assess and estimate the impact of the different 'Boer ondanks natuur' pathways on these different grassland functions or values in order to disclose potential trade-offs and synergies between the grassland functions.

Table 6. Overview of EU and Flemish policy that is relevant for grasslands in the Flemish Ardennes

Policy level	Legal reference	Spatial priorities
Europe	Nature Restoration Regulation	Priority Restoration Areas (ecosystems) Protected Areas
	Common Agricultural Policy	Conservation of permanent grasslands High Nature Value farmland Environmentally Sensitive Areas Preservation of Agricultural Landscapes and Ecosystem Services (e.g. landscape features)
	Habitats Directive	Special areas of conservation
	Nitrates Directive (91/676/EEC)	See Flemish implementation in MAP and PAS
Flanders	Nature Decree	Flemish Ecological Network (VEN) Nature reserves Spatial Implementation Plans (RUPs)
	Nature development decree	Nature development plans
	Programmatic Approach to Nitrogen (PAS)[8]	Nitrogen-Sensitive Natura2000 Sites No-Emission or Emission-Reduction Zones Near Sensitive Habitats
	Manure Action Plan (MAP)[9]	Zero fertilization areas
	Decree on Immovable Heritage	Protected landscapes, heritage landscapes
Province Oost-Vlaanderen	Provincial Functional Ecological Network (FEN)[10]	Core areas: existing valuable nature reserves, Ecological corridors: connections or stepping stones between core areas, Nature development areas: zones with high potential for nature restoration or development.

2.2.5 Participatory stakeholder approach

The scenarios for the Flemish Ardennes have been set up in close collaboration with the Flemish Policy lab. In collaboration with the core group of the Belgian policy lab, three workshops were organized, to which various stakeholders active at local, regional, and Flemish levels were invited. The group of stakeholders consisted of:

[8] Policy framework, designed to address the harmful effects of nitrogen deposition on vulnerable natural habitats, particularly those protected under the EU Natura 2000 network.

[9] Regulatory framework designed to reduce nutrient pollution—particularly nitrogen and phosphorus—caused by animal manure and fertilizers as part of the implementation of the EU Nitrates Directive (1991).

[10] Strategic and legal instrument that identifies where nature conservation and development is prioritized.

- policymakers working in different policy domains (agriculture, nature, environment, water) at various scales ((supra-)local, Flemish);
- researchers from INBO, ILVO and VITO; and
- local farmers.

A first workshop was organized in September 2024. The general aim of the workshop was to gain insights into threats or drivers behind grassland loss on the one hand and on the values or benefits that grasslands provide for the Flemish Ardennes Landscape Park on the other hand. Different grassland values were put forward during the workshop, including values for nature and biodiversity, agricultural-economic benefits, climate and environmental values, and benefits for recreation and tourism (Figure 13).

Figure 13. Results of the first Belgian Policy Lab workshop (September 2024).

A second workshop, focussing on policy targets and scenarios, was organized in May 2025. A first objective of this workshop was to define the policy related to the grassland ambitions that are put forward in the Masterplan of the Flemish Ardennes Landscape Park. A second objective was to gather ideas on which scenarios the participants consider meaningful to model to help strengthen the policy debate around grasslands in the Flemish Ardennes. The workshop was designed taking into account the principles of stakeholder involvement (Rogge et al., 2013). Participants were encouraged not only to think about what is likely or desirable, but especially about what scenario would be of policy interest to gain a better-informed understanding. This exercise encompassed both exploratory scenarios and target-seeking scenarios. Pre-structured templates were provided to support the development of the narratives. Finally, the participants were asked to align their scenarios within the NFF framework, following the workshop format that was developed in the European policy lab (Figure 14; see section 2.1.5).

Figure 14. Belgian Policy Lab workshop

One of the main conclusions of the workshop was that the grassland ambitions outlined in the Master Plan are not well suited to be translated into quantifiable targets that could serve as the basis for target-seeking scenarios. Based on the participants' input, it was therefore decided to use the objectives related to European, Flemish and local biodiversity, and agricultural, environmental and spatial policy that have an impact on grassland changes and grassland functioning as the basis for the target-seeking scenarios. This decision was confirmed during a third workshop, organized in June 2025 with the core group of the Belgian policy lab.

In addition, the workshop showed that although stakeholders recognize various values of grasslands—related to intrinsic, relational, and instrumental values- the participants' main priority lies in developing a future vision for grasslands that aligns with a Nature for Society scenario, in which the instrumental value of grasslands, particularly their value in relation to farm management (e.g., fodder production, manure disposal, part of crop rotation, etc), is considered most important.

2.3 Denmark

2.3.1 General context

The Danish case focuses on national scale land-use policies that are developing currently to address multiple climate and environmental challenges. In particular, the agriculture and forestry sector play a central role in implementation plans for the 2020 Danish Law commitments to reduce GHG emissions by 70% in 2030 compared to 1990 levels. The latest developments have been an agreement in the Danish Parliament (November 2024) to significantly reshape Danish rural landscapes reducing agricultural land and increasing land allocated to nature and to forestry. The implementation plans for this agreement are currently uncertain and the scenario work in MOSAIC aims to explore alternative options to better understand the trade-offs they present.

Table 7. Outline of the policy developments in recent years that sets the context for the Danish land-use scenario work.

Time	Activity
2020	Danish Climate Law stipulating a binding Emissions reduction target in 2030 of 70% below 1990 level.
2021	Political agreement that the reductions in emissions from agriculture should be 55-65%. This indicates that more lenient reduction requirements are asked from the agricultural sector.
2021	Expert group commissioned to advice the Government on the design of a potential Green Tax reform to achieve the climate targets.
2022	Part I: Report on alternative reforms of energy taxes and taxation of CO2 emissions from industry. The recommendations implied a shift in the taxation to tax environmental externalities evenly across emissions sources.
2022	Uptake of the recommendation by the Parliament – introducing a national tax of approx. 100 €/tonne. The Government also introduced tax deductions for firms included in the European Emissions trading system (EU ETS).
2022	National elections and small adjustments to the commissioned work.
2023 Winter	Part II: Report on alternatives for regulation (taxes/subsidies/mandatory restrictions) of agricultural emissions (CO2e – i.e., CH4, N2O, and CO2 from soils and biomass).
2024 Spring	Negotiations of the recommendations in a forum with participants from the agricultural interests organisation, nature conservation organisations, the government and a number of other stakeholders. The negotiations of Climate policy instruments coincided with the challenges faced by the sector to meet the 2027 targets for the Water Framework Directive (WFD). Due to the overlap between both the emissions sources and the potential solutions the negotiated agreement between the parties (called the Tripartite Agreement)

	aimed to address both the climate target for 2030 and 2050 climate and water quality as stipulated in the WFD.
2024 Autumn	The Tripartite Agreement[4] was negotiated in Parliament and supported with a large majority covering both parties at the left and the right of the Government. The agreement stipulates that reafforestation and peatland restorations are key land-use measures to be implemented to achieve both 2030 targets and 2045* targets. Specifically, the target for peatland restoration is 140.000 ha by 2030. The afforestation targets are 250.000 ha by 2045. Furthermore, there are specific targets for the location and the type of forests that the agreement includes. The planned forest types range from forest generated from natural succession, forest priorities for recreational activities close to cities and forest managed with climate mitigation as the main purpose.

**Tightened climate targets have pushed 2050 targets to 2045 during the political negotiation on implementation of the Climate Law.*

The Danish case study focuses on understanding the least-cost approaches to achieving the targets in the tripartite agreement. The environmental targets include the policy targets for the land-use sectors on GHG emission reductions, the water quality targets from the Water Framework Directive, and contributions to biodiversity targets. There are also targets for specific policy measures, afforestation, peatland conservation and forest conservation (see Table 7 above).

An important dimension in the policy debates has been the extent to which current land-use policies are ineffective due to displacement effects. Therefore, the Danish case study also includes an analysis of the evidence of indirect land-use change (iLUC) and displacement effects. The analysis will include displacement effects at local and global scale. At the local level, this part of the modelling aims to analyse the potential indirect effects of agri-environmental programs that aim to support sustainable land use. A panel data analysis is used to model local spillover effects of participation in the Environmental Grassland Program. This program compensates farmers for the extensification of parts of their land. We use this programme as an example of a policy instrument to incentivise sustainable land use and investigate whether this measure has created indirect land-use effects at the farm level. This work is a joint effort between WP3 and WP4 research. The data for the analysis is based on the same agricultural land-use layers as the TargetEconBES model (described further in section 2.3.2).

At the global level, the study will focus on the indirect land-use change impacts of the European Green Deal on the other parts of the world. Potential displacement effects of land-use change initiatives are also relevant at the regional level. Policy measures to reduce GHG emissions from changes in land use may not be effective in terms of global emission reductions if they only create land-use pressures in other regions of the world. A key component of the European Green Deal is the preservation and restoration of nature. The biodiversity strategy sets targets to protect 30 percent of the EU's terrestrial area, with 10 percent of this area under strict protection. Currently, only 3.5 % is under strict protection (Robuchon et al., 2025; Wilkki & Reeve, 2021). In addition, planting 3 billion trees and allocating 10 percent of the total agricultural area under high-diversity landscapes are among the targets set for 2030. On the intensive margin, the strategy aims to reduce the use of chemical pesticides and fertilizers (Wilkki & Reeve, 2021). These measures could have land-use impacts beyond EU borders (Di Fulvio et al., 2025; Fischer et al., 2024; Meyfroidt et al., 2013). Such displacement effects have been central to policy debates but not supported by land-use modelling work. In MOSAIC, the Danish team will also contribute to the development of land-use models that can address such regional and global-scale policy questions.

2.3.2 Modelling methods

The TargetEcon model is used for the scenario modelling (Filippelli et al., 2024; Termansen et al., 2024). This model is designed to identify synergies between environmental objectives in a spatially specific environmental economic analysis. This approach involves the specification of several optimization problems, seeking to meet combinations of environmental goals at lowest costs to society.

The model is a mixed integer linear programming social planner model. The objective function is the aggregated cost across all field and forest parcels of achieving various environmental targets. The environmental targets include the policy targets for net zero GHG emissions, the water quality targets from the Water Framework Directive (WFD), and contributions to biodiversity targets. There are also targets for specific policy measures, afforestation and forest conservation. Figure 15 gives an illustration of the modelling framework.

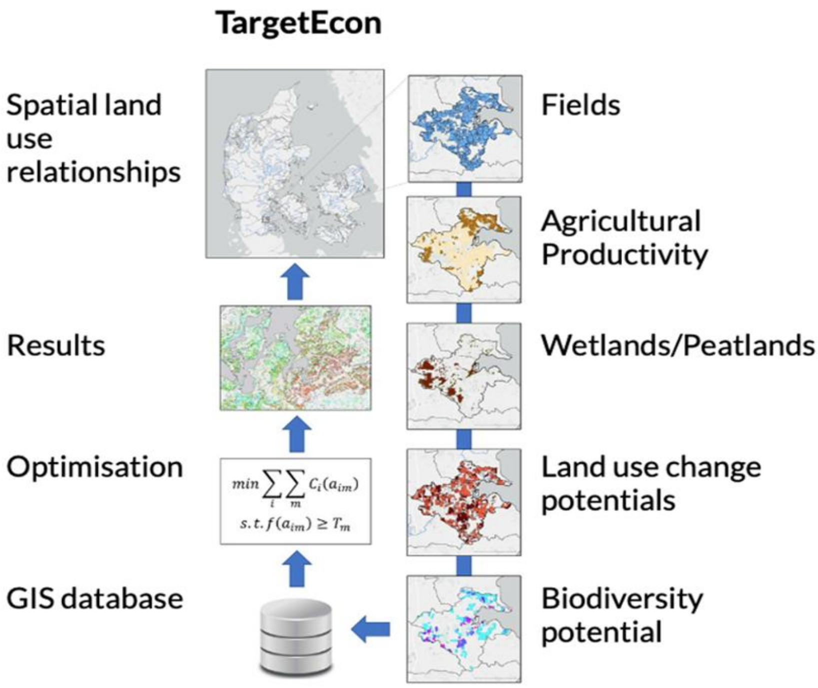


Figure 15. Illustration of TargetEcon

Scenarios exploring the synergies between reductions in GHG emissions, water quality improvements and biodiversity conservation have been reported in (Hansen et al., 2025). The work results from using the model to support the Danish Council on Climate Change.

Indirect land-use change impacts will be modelled using the Simplified International Model of Agricultural Prices, Land use and the Environment – Gridded version (SIMPLE-G) (Baldos et al., 2020; Haqiqi & Hertel, 2025). A detailed technical description of the model is found in

Haqiqi & Hertel (2025). The model is a spatially explicit, multi-regional, partial equilibrium model that integrates economic theory with biophysical information to analyse the impacts of sustainability policies at different geospatial scales. The main components of the model are demand, supply, and trade. On the demand side, SIMPLE-G models aggregate crop demand at the regional and global levels. On the supply side, crop production and demand for inputs (such as land and fertilizer) are modelled at the grid-cell level. International trade follows the Armington approach, in which imported and domestic goods are considered imperfect substitutes (Armington, 1969). SIMPLE-G is suitable for analysing market-mediated spillover effects of land-based policies. Conservation policies that restrict land use can be modelled at the grid-cell level, allowing for the determination of where land is taken out of production, as well as the amount of land (Haqiqi & Hertel, 2025; Wang, 2024).

The model will be customized to the EU case. The initial equilibrium in SIMPLE-G is based on baseline spatially explicit data for economic and biophysical variables, as well as elasticity parameters. Empirical estimations from WP3 and previous literature will inform the elasticities used in the model.

2.3.3 Exploratory scenarios

The Danish case study has focused on target-seeking scenarios for Task 4.1 (see section 2.3.4). This focus is closely aligned with the objectives of the Danish policy lab's work on how to achieve Danish policy targets on reduction in net CO2e emissions through land-use change initiatives, afforestation in particular. Thus, while target-seeking scenarios at national scale will be the main focus of the work by the Danish partners in the MOSAIC project, exploratory analyses will be conducted as well but more independently from the Danish case but at a larger scale (EU – Global) and explore the cross-scale interlinkages of land-use policy initiatives. In particular, the study seeks to explore the global indirect land-use change impacts of the European Green Deal using SSP scenarios with the SIMPLE-G modelling framework. The key drivers of demand for land in the model are population and income. The baselines for these global and regional drivers will be adjusted to align with SSP scenarios. This research will specifically focus on SSP1, SSP2, and SSP3. The three scenarios represent three different levels of future pressure on land resources. Specifically, the scenarios reflect limited, modest, and high pressures on land use, respectively (Popp et al., 2017). In addition, SSP2 projection of population, GDP, and technology development closely follows the historical trend (Popp et al., 2017). The SSP2 has been used as a baseline in previous comparable modelling studies (e.g., Zhong et al., 2024). Therefore, to analyse the indirect land-use change effects under different land-use futures while ensuring comparability with other studies, these three SSPs will be included. The exploratory scenarios for the EU will be based on the SSPs downscaled by the EU case study.

2.3.4 Target-seeking scenarios

As outlined above, the policy context of the Danish case study is the Tripartite Agreement which was finally negotiated and approved in the Danish parliament at the end of 2024.

Some of the targets agreed are very specific in terms of the number of hectares of specific changes in land use, but there are still large uncertainties related to where the land-use change will be required to meet climate and water quality targets. It is also not known how the land-use change will be incentivised or whether compulsory set aside of agricultural land will be included in the policy mix. Furthermore, on top of the binding targets on climate change mitigation and the WFD targets on good ecological status, the plans also have more vaguely formulated aspirations to enhance recreational and biodiversity benefits.

To build scenarios in MOSAIC which can help the development of alternative land-use transitions, we put most emphasis on the scenarios for afforestation. Models will be run to describe alternative reafforestation plans and how they can contribute to the various tripartite agreement targets. The inputs for the scenarios are the land-use model inputs in the TargetEcon model and the targets defined in the Tripartite agreement. This aligns well with the work done with the Danish policy lab as implementation of reafforestation and peatland conservation is the mandate of Klimaskovfonden, the Danish MOSAIC partner leading the Danish policy lab. A stakeholder workshop was held to formulate the domain of the alternative scenarios (see section 2.3.5). Preliminary modelling outputs have been reported in Hansen et al. (2025). This paper has explored the synergies between the targets for the tripartite agreements but has not explored the role of afforestation in detail. This will be the focus in the next steps.

2.3.5 Participatory stakeholder approach

In December 2024, the UCPH team hosted a stakeholder workshop to obtain input from stakeholders on how to scope relevant afforestation scenarios for the tripartite agreement targets. The NFF scenarios developed by the KIT team for the EU case were adapted to suit the Danish case study (Table 8).

Table 8. A summary interpretation of the perspectives in the NFF in the context of land-use change in the tripartite agreement and the stakeholder workshop.

Nature For Nature	Nature As Culture	Nature For Society
The priority land use for nature conservation in Denmark are forests. The agricultural land in Denmark is intensively managed and has low biodiversity value in general. However, taking agricultural land out of production in areas in close proximity to forests or other nature areas of high biodiversity can enhance the biodiversity protection impact of agricultural areas that are set aside. Taking agricultural land out of production in areas with high pressures on water quality will also generate higher value of afforestation than areas where the water quality is not under pressure. Furthermore, the type of afforestation is also believed to be important for the biodiversity potential of the land-use change	For this perspective, people's use of new afforestation areas for recreational activities is a key element. This means that afforestation close to cites will have a higher potential of generating value under this perspective. This is particularly true in areas with few existing recreational opportunities. This makes the geographical distribution of the land-use change important for the values of future landscapes. For a relatively small segment of the Danish population, afforestation also provides increasing hunting opportunities. Revenues from leasing out hunting rights is	Cost effectiveness is an important criterion in the Danish Climate Law and also in the implementation of the tripartite agreement. The cost effectiveness of afforestation and peatland restoration as climate mitigation measures are therefore a core rationale for the scenarios under this perspective. The scenario work for the Danish climate council has highlighted the synergies in joint implementation of the WFD, Climate targets and biodiversity conservation. This implies that scenarios for multiple targets are critical for this perspective. The WFD and the biodiversity potentials are geographically

activities. Land-use change through natural succession is therefore a priority for afforestation under this perspective. Finally, set aside of large continuous areas is also priority for stakeholders having this perspective on the implementation of the tripartite agreement.	also a potential income source for landowners. An important human health aspect is the protection of ground water reservoirs. Concerns about nitrate levels in drinking water is therefore a priority for the future land-use planning under this perspective.	localised, making spatially explicit scenarios highly relevant. On the contrary, the value of the contribution to climate change mitigation is independent of geography.

2.4 Hungary

2.4.1 General context

The Sand Ridge region in the Danube-Tisza Interfluve, within the Hungarian Great Plain, grapples with severe water scarcity due to recurrent droughts, significantly affecting agricultural activities and the livelihoods of local farmers. The Sand Ridge region can be described as a mixed landscape of arable land, forest, animal husbandry, fishponds, saline wetlands, fen meadows and sand dunes. It is a historical agricultural landscape; a semi-arid landscape with dry vegetation. The combination of slightly decreasing annual precipitation, increasing temperatures due to climate change, water management focusing on draining the waters from the landscape, agricultural and other land-use (primarily forestry) practices, and oil and well drilling activities have compounded the water shortage challenges in recent decades.

While local and regional actors acknowledge water scarcity issues, they have differing beliefs and diverse expectations regarding potential solutions. Some farmers, supported by the local government and associations (the most notable one is the 'Kiskuns for the Water' Association), have initiated community-level collaborations to retain water in the landscape, reallocate land for water, and restore the more traditional land uses (e.g., extensive animal husbandry) in order to meet biodiversity and climate objectives and enhance agricultural efficiency. Their landscape restoration methods apply small-scale, low-tech nature-based water retention measures, where the beneficial impacts are not always immediate but clearly embodiy a different vision of the landscape in which water regains its ecological and socio-economic functions compared to the currently dominant one that treats water as a purely engineering issue. However, a larger part of farmers and other local stakeholders anticipate solutions from external actors, primarily expecting centralized governmental solutions in the form of large-scale, costly engineering interventions to mitigate water shortages.

The Hungarian case study aims to gain insights into (1) the social and power dynamics affecting land-use changes, (2) the determinants shaping decision making at local and regional levels, and (3) elucidate effective methods for instigating transformative change with diverse local stakeholders possessing distinct interests, power and knowledge regarding their land and agriculture. Among the research intervention methods, the Hungarian case study favours participatory research tools, including participatory scenario development based on the Natures Futures Framework.

2.4.2 Modelling methods

The Hungarian case study cooperates with partners at KIT to utilise the CRAFTY-Europe model for the modelling needed for the case. The Hungarian case study focuses on local, bottom-up dynamics (i.e., farmers initiated local nature-based interventions) and aims to connect the local dynamics to regional and national governance levels through the policy lab. CRAFTY was chosen to support local and regional stakeholders to gain a broader picture of drivers of land-use change and subsequent actual and potential changes in land-use patterns. Utilising CRAFTY-Europe will allow the consideration of larger European scale land use and climate change impacts, as well as the consequences of policy interventions at EU and national level. This will enable the development of a nested approach to complex landscape dynamics and their management, whereby consequences of larger scale changes are inferred for the case study area (the Sand Ridge).

2.4.3 Exploratory scenarios

The Hungarian case will focus on the four Tier 1 SSPs/RCPs scenarios. The European scale scenarios used in the European case (seesection 2.1.3) provide inputs that will be used to produce land-use outcomes for Hungary and allow for analysis at the national and regional level. Spatially-explicit inputs include vegetation productivities (natural capitals) at a 1km resolution provided by RCP-based projections from LPJ-GUESS (Smith et al., 2014), and the socio-economic capitals produced by KIT at a 5km resolution (Raymond et al., Under Review). Additionally, SSP-specific national commodity demands for Hungary are provided by PLUMv2 (Alexander et al., 2018).

2.4.4 Target-seeking scenarios

NFF narratives were developed through a multi-step process combining qualitative analysis and stakeholder validation (see section 2.4.5). First, interview transcripts were analysed to identify key thematic nodes shaping the emerging narratives. As part of this, negative narratives were inverted to generate positive future scenarios grounded in the interview material. Second, three NFF narratives were presented during the half-day workshop to invited experts, who engaged with them through interactive exercises and discussions. Participants contributed disciplinary insights and long-standing experiential knowledge to refine and validate the scenarios. Finally, the expert feedback gathered during the workshop was used to revisit the original three narratives and integrate the new aspects and ideas shared during the workshop into the interview-based original versions. The integrated scenarios are presented in

Table 9 the final result of this process.

2.4.5 Participatory stakeholder approach

The narrative validation workshop was held utilising the Nature Futures Framework (NFF), focusing on Hungary's Sand Ridge (Homokhátság) region. The workshop brought together policy experts, decision makers, and public administration professionals from local and regional to national level. While most participants were already known to the MOSAIC team, a few new stakeholders contributed fresh perspectives, offering potential for future collaboration.

The Nature for Nature scenario received limited support. Participants found it unrealistic due to its exclusion of human presence in certain regions, they emphasized the need for landscape management. In contrast, the Nature as Culture scenario was more positively received for its emphasis on traditional land use, however the invited participants underlined the limitation of this future scenario as well. The Nature for Society scenario inspired the participants' imagination the most and this was the one which they could relate to most from the 3 future scenarios.

While the workshop successfully validated the scenarios, it also revealed challenges in synthesizing stakeholders' perspectives. For a deeper and further understanding of the policy context and policy targets, face-to-face, semi-structured interviews with policy experts were conducted. As part of the expert interviews, officials from ministries, representatives of environmental NGOs, experts affiliated with state institutions, and regional-level political stakeholders were engaged with.

Stakeholders widely viewed current policy targets as not clearly defined and as requiring further translating to the landscape level. The stakeholders agreed that a shift in approach has taken place in water related policy in Hungary, which prioritizes water retention over the immediate drainage of temporary excess water. However, there were differing opinions as to whether this shift has only just begun, is currently underway, or has already been fully implemented.

A reoccurring negative theme which was mentioned especially in the NGO and expert interviews was the systematic side-lining of the public interest in land and water governance. These stakeholders perceived decisions to be increasingly shaped by short-term political calculations and powerful private interests, rather than long-term ecological or societal needs. As a result, land-use practices that severely undermine sustainable water management continue to dominate, exacerbating environmental degradation.

In sum, the stakeholder workshop and semi-structured interviews revealed that there is large agreement among participants on the recognition of the region`s water scarcity problem, while opinions still diverge concerning the potential solutions and specific courses of action.

Table 9. Validated NFF narratives after the Hungarian expert workshop

Nature For Nature	Nature As Culture	Nature For Society
Following the partial removal of artificial drainage systems, the regeneration of wetlands, marshes, fens, and grasslands has started in several areas. This process does not occur spontaneously everywhere and often requires active ecological restoration. As a result, several water-dependent species have returned to the landscape, including storks, swallows, amphibians, and waterbirds but among these, humans also appear as a species connected to water. Species that form the basis of the food chain have also regenerated, enabling the return of these species. Although nature is not directly managed by humans, its regeneration does not happen automatically, as the spread of invasive species, declining groundwater levels, and the impacts of climate change often hinder the return of wilderness-like conditions. Achieving	The relationship between nature and humans in the Sand Ridge is not merely functional, but deeply cultural. Water management is not a technocratic system, but a communal practice – a form of knowledge passed down through generations. The area itself can be understood as a reservoir and as part of a system of seepage pathways. The landscape has regained its mosaic structure: pastures, saline lakes, small-plot arable fields, orchards, and vineyards alternate with one another, while water-affected habitats are integrated into the heart of the farms. The *tanya* – as an element of the cultural landscape and symbol of the local way of life – is a value to be preserved; however, its future is only sustainable if it plays a genuine role in contemporary land use. Agriculture is not an industrial	By 2030, the Sand Ridge region has transformed into a climate-resilient landscape characterized by a regenerative mindset and decentralized food production. People no longer flee from this area; instead, the land holds them. Water-retentive land use has enabled household-level vegetable and fruit cultivation – where workforce is available – as well as arable farming adapted to natural carrying capacity and water efficiency. In place of former decaying orchards, new varieties better suited to the altered climate are being introduced – for example, drought-tolerant alternatives are replacing former apricot trees. Water is available not only for people, but also for plants, shade-providing trees, and thereby the entire ecosystem. Special attention is given to forest belts in the landscape. Ecosystem services such as

desirable ecological conditions cannot be envisioned through isolated interventions, but rather through a holistic landscape-scale approach.	activity, but a way of life that protects habitats while maintaining the countryside as a home. The landscape of the Sand Ridge is shaped by local knowledge, traditional farming practices, and the rhythm of local communities, following a regional logic that recognizes that the countryside cannot be sustained by a single universal nationwide system. Nature does not persist in separation but is embedded in the fabric of human culture where it has a future, and where communities are able to reconnect with it.	pollination, shading, soil retention, and water retention not only serve as the foundation of production but are also under legal protection. The future landscape is shaped by agricultural areas, while settlements are becoming more nature oriented.

2.5 Portugal

2.5.1 General context

The Alentejo Region, with 2.7 million hectares encompassing approximately one third of Portugal's territory, is characterised by low population density, associated with trends of rural depopulation and land abandonment, and a mix of land uses, mainly related to agriculture, livestock, and agroforestry. Nevertheless, the region has undergone significant transformations in land use and landscape in recent decades, primarily driven by economic and policy factors (Silveira et al., 2018). These changes are associated with the intensification of farming systems, such as the monocultures of olive groves and almonds, as well as the expansion of large-scale solar farms, which significantly impact soil quality and fertility, landscape integrity, and biodiversity loss. Intensive farming systems require the use of fertilisers and pesticides, as well as high water and energy consumption. Simultaneously, solar farms are also expanding due to the region's high solar potential and low land costs. These competing land-use claims increasingly overlap with the region's natural capital, including habitats, protected areas, and culturally significant landscapes.

While contributing to the region's economic growth and national energy transition goals, the shift from extensive to intensive agriculture, coupled with the "sprawl" of large-scale solar farms, often conflicts with nature conservation efforts and traditional land-use practices fundamental to preserving Alentejo's landscapes. One of them is the montado, an agrosilvopastoral system that naturally promotes biodiversity and provides ecosystem services. Moreover, the Mediterranean Region, where the Alentejo is located, is particularly vulnerable to climate change under high warming projections, with increased heatwaves and droughts (IPCC, 2023). Increased water stress due to high demand for irrigation from intensive agriculture is a pressing issue.

The complexity of this general context necessitates a comprehensive understanding of the drivers behind land-use decisions and their environmental and socio-economic consequences. The Nature Restoration Law is a relevant new framework to consider as it mandates EU member states to restore at least 30% of degraded habitats by 2030, escalating to 60% by 2040 and 90% by 2050, aiming to reverse biodiversity loss and enhance ecosystem resilience (European Parliament and Council, 2024). In Alentejo, this translates to restoring habitats affected by intensive land-use practices, ensuring the conservation of endemic species and the sustainability of ecosystem services. Integrating nature into land-use planning aligns with these legal obligations and promotes a balanced approach to regional development.

Given this general context, the Portuguese case aims to develop exploratory and target-seeking scenarios, focussing on the nexus between farming systems, nature, and energy.

2.5.2 Modelling methods

The modelling method in the Portuguese case will be based on the agent-based land-use model CRAFTY. We are developing a Portugal-specific version, CRAFTY-PT, which is a downscaled version of CRAFTY-Europe, where the inputs (regional commodity demands, natural and non-natural capitals) are tailored to the Alentejo Region (Figure 16).

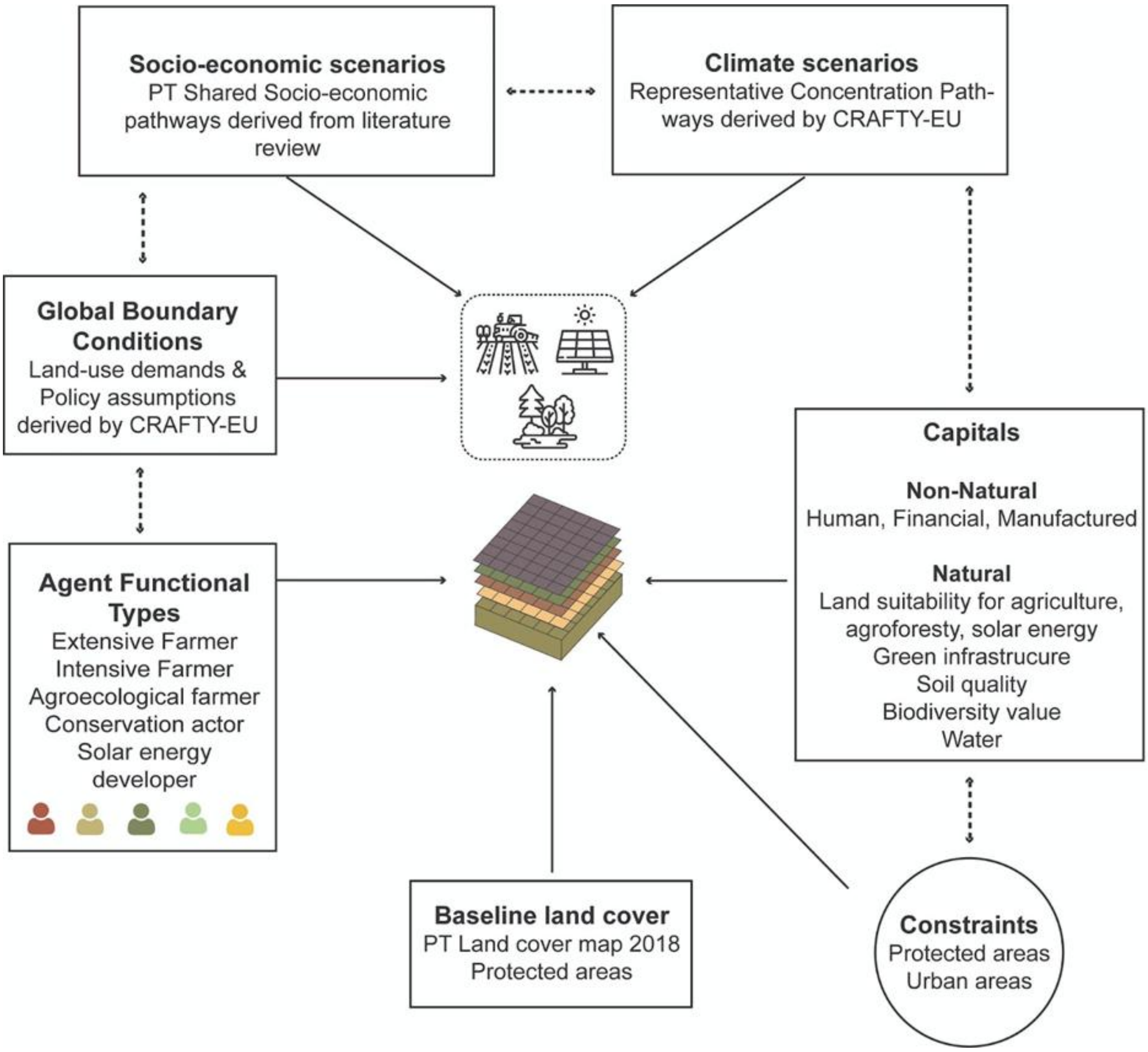


Figure 16. Simplified graphical representation of the information flow between models within CRAFTY-Europe and scenario-specific inputs to CRAFTY-PT

CRAFTY-PT simulates land-use changes in the Alentejo Region by modelling the interaction between external and internal inputs. The external inputs include socio-economic scenarios (Shared Socioeconomic Pathways) and climate scenarios (Representative Concentration Pathways), as well as global boundary conditions such as regional land-use demands and policy assumptions derived from CRAFTY-Europe. These factors provide the overarching context within which land-use decisions are made.

The internal inputs are tailored to the Alentejo Region and include the definition of a set of agent functional types (AFTs), land-use constraints (e.g., protected and urban areas) and a baseline land cover map from 2018. The AFTs are related to extensive and intensive farmers, agroecological farmers, conservation actors, and solar energy developers. Additional internal inputs include spatially explicit layers of natural (e.g., land suitability for agriculture, solar energy potential, biodiversity value, water availability, and infrastructure) and non-natural capitals (e.g., human, financial and manufactured) that inform where and how these agents operate. We will collect natural and non-natural capitals tailored to the Alentejo Region based on European and national databases.

Together, the external and internal inputs enable CRAFTY-PT to simulate how different agents interact with the landscape and respond to policy and environmental change, generating spatially explicit land-use outcomes under future scenarios.

Within the modelling methods, we also integrate a spatially explicit Geographic Information System (GIS): Green Infrastructure & land suitability model to complement the target-seeking scenarios (Figure 17) (Magalhães et al., 2018). This model integrates concepts of ecological (green) infrastructure (Cunha & Magalhães, 2019, 2025) and land suitability (Magalhães, 2016; Poggi et al., 2018) to address the socio-ecological complexity of the Alentejo region. By acknowledging the complex interdependencies between ecological, social, and economic systems, this approach emphasises the interconnectedness of people and nature.

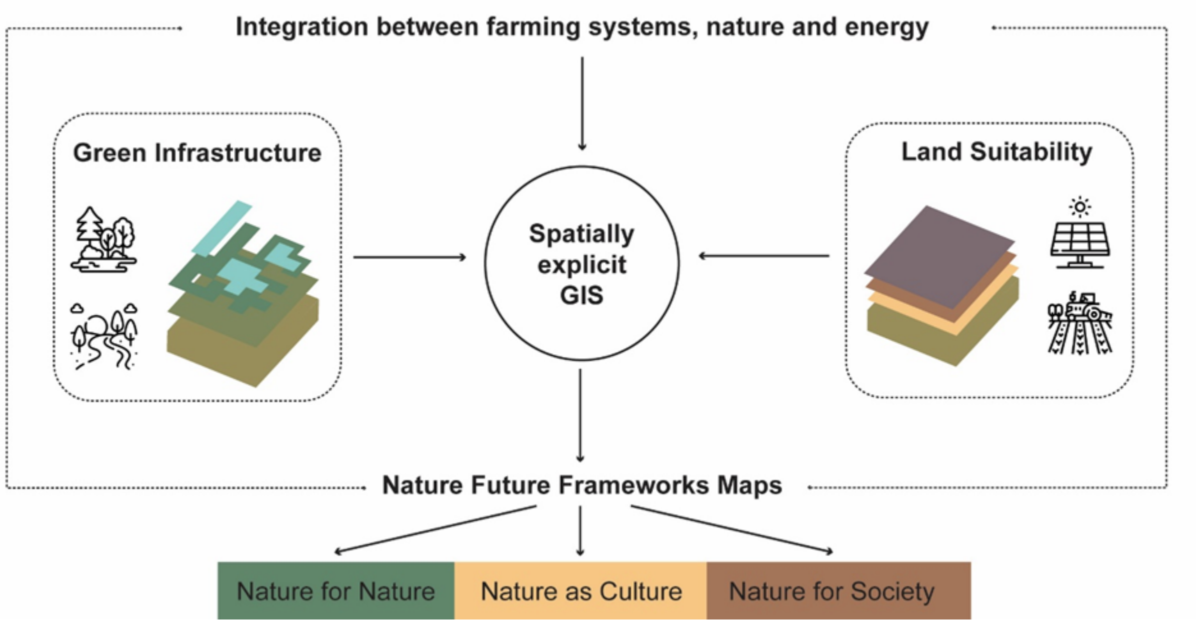


Figure 17. Conceptual approach of the spatially explicit GIS linking green infrastructure, land suitability, and NFF policy goals to support the integration of farming systems, nature, and energy.

The guiding principle of the present modelling approach is to test the integration and balance of farming systems, energy, and nature under socio-economic scenarios and climate change projections, covering both exploratory and target-seeking scenarios. This involves using the CRAFTY-PT model to examine how different SSPs/RCPs combinations affect land-use decisions in the Alentejo region (exploratory scenarios) and to develop positive scenarios focused on the relationship between nature and people (target-seeking scenarios) through the NFF and the explicit GIS: Green Infrastructure & land suitability model.

Results from CRAFTY-PT will relate to identifying potential shifts in land allocation between extensive and intensive farming systems, promoting habitats, ecosystems, and natural resource conservation, as well as solar farm deployment, under different future socio-economic and climate change projections.

Results from the spatially explicit GIS model will support the visualisation of the three value framings: Nature for Nature, Nature for Society, and Nature as Culture, by translating narrative-based scenarios into maps. This approach enables the representation of abstract values and priorities in concrete land-use patterns, making it possible to explore, compare, and communicate alternative positive futures for the Alentejo Region.

Together, these modelling methods aim to develop actionable knowledge related to exploratory and target-seeking scenarios that can support policymakers and land users in developing innovative policies and strategies for sustainable land management in the region, considering climate change uncertainty.

2.5.3 Exploratory scenarios

Exploratory scenarios for the Portuguese case are developed using the CRAFTY-PT model to simulate future land-use change at the regional scale. The model applies Tier 1 SSPs/RCPs combinations to elaborate scenarios based on alternative socio-economic and climate pathways, exploring the growing competition among the domains of farming systems, nature, and energy.

The first step in developing exploratory scenarios for the Portuguese case study involved a literature review of national and regional studies that apply SSPs/RCPs frameworks. This review aimed to identify relevant data sources on socio-economic and climate variables, as well as existing scenario-based initiatives that could inform and align with the modelling process in CRAFTY-PT. The review ensures that the exploratory scenarios developed are consistent with national policy frameworks and grounded in available empirical and projection-based evidence. In this sense, Table 10 synthesizes key scenario-based studies and highlights their relevance to the domains of farming systems, nature, and energy, which are central to the CRAFTY-PT model.

Table 10. Synthesis of the SSPs/RCPs studies elaborated at the national and regional levels in Portugal.

Study	Scale	SSPs/RCPs Use	Alentejo Specific	Relevant Information on Agriculture and Energy
RNC2050 - Roadmap for Carbon Neutrality 2050 (Council of Ministers, Portuguese Government, 2024)	National	National scenarios inspired by SSP	No	Focus on decarbonization; the “Camisola Amarela” scenario promotes low-carbon agriculture and expansion of renewable energy.
RNA2100: WP2 – Climate Projections, Extremes, and Indices	National and Regional	Uses EURO-CORDEX regional climate simulations with RCP2.6,	Yes	Provides RCP-based projections for temperature, precipitation, drought, and heat extremes; disaggregated by region, including Alentejo.

(Soares, Lima, et al., 2024)		RCP4.5, RCP8.5		
RNA2100: WP3 – Emissions Scenarios, Narratives, and Socioeconomic Trajectories (Soares, Dias, et al., 2024)	National and Regional	Uses SSPs-RCPs Tier 1 (SSP1–2.6, SSP2–4.5, SSP3–7.0, SSP5–8.5)	Yes	Narratives include adaptation for agroforestry, water resources, wildfire and drought risks, and potential expansion of solar photovoltaic infrastructure.
D3 - Regional Climate Projections and Scenarios with High Spatial and Temporal Resolution (CCDR Alentejo, 2023a)	Regional	EURO-CORDEX RCMs using RCP2.6, RCP4.5, RCP8.5	Yes	Presents high-resolution projections of climate indicators across Alentejo sub-regions; includes seasonal and extreme climate impact analyses relevant to agriculture.
D5 - Regional Strategy for Climate Change Adaptation in Alentejo (CCDR Alentejo, 2023b)	Regional	RCP2.6, RCP4.5, RCP8.5	Yes	High-resolution projections; focuses on irrigation stress, heat extremes, and vulnerability of rain-fed crops. Energy is not directly addressed but climate context is highly relevant.

Soares, Lima, et al. (2024), focus on SSPs/RCPs combinations, providing specific information on the Alentejo Region. Using insights from the RNA2100, a scenario matrix (Table 11) has been elaborated to guide land-use dynamics in CRAFTY-PT. This matrix aligns with Tier 1 SSPs–RCPs combinations and incorporates both global socio-economic narratives and their regional interpretations for the Alentejo context. It provides a structured foundation for exploring the interactions and trade-offs across farming systems, natural systems, and energy domains under varying climate and policy scenarios. The matrix will enable CRAFTY-PT to simulate how diverse land-use agents may respond to environmental pressures, policy interventions, and shifting resource availability in a region particularly vulnerable to climate change.

Table 11. Exploratory Scenarios Narrative Matrix for CRAFTY-PT.

Scenario	SSPs-RCPs	Global Narrative	Regional Interpretation (Alentejo)
Sustainable Landscape	SSP1-RCP2.6	Sustainability and cooperation	Widespread promotion of extensive farming, agroecological practices, and nature restoration. Green corridors and ecosystem restoration programs are expanded. Solar energy is restricted to GO TO AREAS (Simoes et al., 2023) to minimize land conflict.
Middle of the Road	SSP2-RCP4.5	Continuation of current trends	Mix of intensive and extensive systems. Some support for sustainability exists, but market forces still drive the cultivation of olive and almond monocultures. Green infrastructure expands slowly. Solar energy expansion is moderate, but it is emerging with new land-use conflicts.
Fragmented & Unequal	SSP3-RCP7.0	Regional rivalry and protectionism	Reduced environmental governance. Agricultural intensification increases in profitable areas; elsewhere, land is abandoned. Biodiversity loss accelerates. Large-scale solar development faces minimal regulation, leading to increased land competition.
Fossil-Driven Growth	SSP5-RCP8.5	Rapid economic growth, fossil-fuel reliance	High-pressure agribusiness expansion, especially intensive olive and almond plantations. Nature-based solutions are sidelined. Large-scale photovoltaic infrastructure is expanding aggressively, leading to widespread conflicts with agriculture and ecosystems.

The above exploratory scenarios narratives are associated with quantitative parameters extracted from the literature review and database, covering demographic trends, economic growth, water stress projections, and land-use demand across the four SSPs/RCPs scenarios.

2.5.4 Target-seeking scenarios

The target-seeking scenario approach supports the development of three Nature Futures Framework (NFF) scenarios through pathway narratives complemented by the construction of a spatially explicit GIS model. The three scenarios are aligned with key policy targets across European, national, and regional (Alentejo) levels and were discussed with regional stakeholders during a workshop held as part of the Portuguese Policy Lab initiative. By combining policy objectives with spatial criteria for green infrastructure and land suitability, this methodology allows for the generation of regionally grounded and differentiated options that reflect the value perspectives of the NFF:

- Nature for Nature, prioritizing ecological integrity and biodiversity;

- Nature for Society, emphasizing human well-being and ecosystem services; and
- Nature as Culture, valuing the historical and cultural ties between communities and their landscapes.

Given the focus of the Alentejo case study on the nexus between farming systems, nature, and renewable energy, the NFF narratives are shaped around three thematic policy clusters: biodiversity, agriculture and renewable energy. The main targets that structure the scenario narratives are summarized in Figure 18. A synthesis of the narrative pathways corresponding to each of the three NFF perspectives is presented in Table 12.

Figure 18. Overview of the EU policy target objectives in thematic clusters of the Portuguese case.

Table 12. Synthesis of the stakeholder-validated narrative pathways according to the three thematic policy clusters

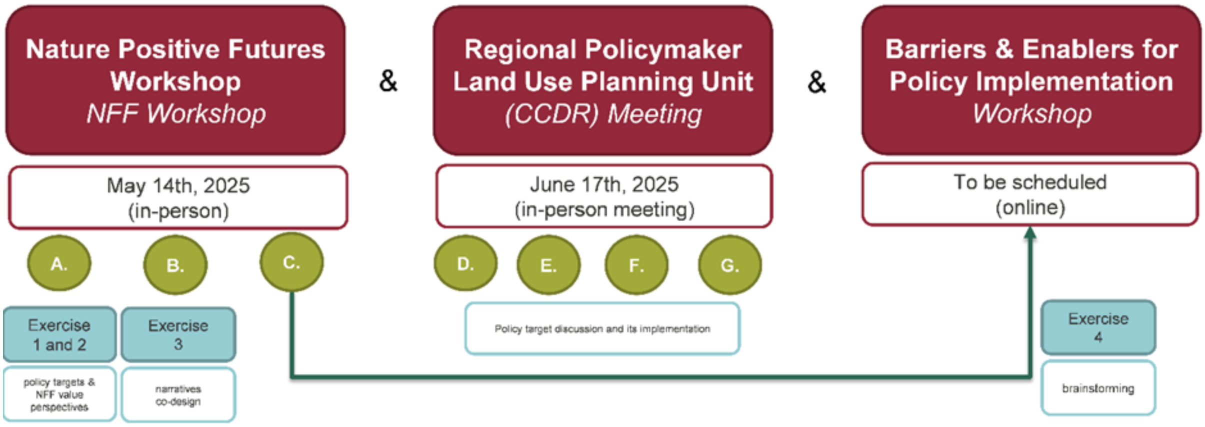
	Nature for Nature	Nature as Culture	Nature for Society
Biodiversity – Policy Target: At least 30% restoration of terrestrial habitats and >30% increase in protected areas	Biodiversity conservation is prioritized through Green Infrastructure (GI), aiming to protect and restore up to 60% of the territory by 2040, including strict protection for 10% of habitats and restoration of key ecological corridors. Local nurseries and seed networks support native vegetation, and the *Montado* is preserved as a biodiversity-rich system.	Cultural landscapes such as the *Montado* and traditional agricultural systems are restored and integrated into protected areas, enhancing both ecological and cultural connectivity. Community initiatives support the transmission of traditional knowledge and reinforce the symbolic and identity value of the landscape.	Nature is valued for ecosystem services, sustainable income, and well-being, with protected areas expanded and ecological functions recognized beyond formal boundaries. Biodiverse systems like the *Montado* and productive shrublands support rural resilience and alternative income sources.

Agriculture-Biodiversity – Policy Target: Increase biodiversity index and high-diversity landscape features in agriculture	Farming adapts to soil quality, promoting organic and regenerative practices while restricting intensive use in ecologically sensitive areas, such as GI. Agroecological mosaics and multifunctional buffer zones enhance habitat connectivity and biodiversity.	Small-scale regenerative farming is promoted, with local communities leading decisions that align agriculture with cultural heritage. Traditional rainfed systems and polyculture are supported to preserve landscape identity and ecological function, especially near urban areas.	Sustainable intensification and precision agriculture improve ecological outcomes in intensive systems, complemented by hedgerows, water retention features, and riparian restoration. Food production near cities supports circular economies and ecosystem service enhancement.
Policy target: Achieve 42% renewable energy production	Solar farms are guided by nature-inclusive principles, ensuring that energy production supports ecological restoration and biodiversity. New large-scale solar farms are no longer allowed. Efforts focus on upgrading existing ones with advanced technologies and restoring the land ecologically after decommissioning.	Solar power farms are developed with respect to landscape coherence, cultural heritage, and ecological values. Large-scale installations are generally prohibited, except in degraded or low-value landscapes identified locally. Small to medium-scale projects are limited to ecologically less sensitive "GO TO AREAS" (Scenario 4 by Simoes et al., (2023))	A diverse mix of solar farms, agrivoltaic and ecovoltaic systems, and energy communities supports regional energy self-sufficiency and contributes to national renewable goals. Large-scale solar plants are encouraged in ecologically less sensitive or degraded areas, while *montado* landscapes are strictly protected for their ecosystem services. Agrivoltaics aid in food and energy co-production, and ecovoltaics enhance biodiversity.

2.5.5 Participatory stakeholder approach

Engaging with local stakeholders is central to the development of target-seeking scenarios in the Alentejo case study of the MOSAIC project. The Policy Lab offers a space for participatory co-design and validation, enabling regional actors to shape narratives that reflect both ecological ambitions and territorial realities. This participatory stakeholder approach has been evolving through an in-person workshop, a meeting with the regional policy maker (CCDR-Alentejo), and a second workshop planned for late 2025 (Figure 19).

The first NFF workshop took place in May 2025, bringing together stakeholders from regional public administrations and associations. The main objectives for the session were to frame the objectives of European policies for the region within the scope of the Alentejo Policy Lab, to explore how to implement these objectives and to deepen the narratives of nature-positive futures. During the session, the preliminary vision for a nature-positive Alentejo was presented alongside an initial evaluation on the draft NFF pathway narratives. Participants engaged in three structured exercises to evaluate the relevance and feasibility of selected EU policy targets and environmental objectives - related to biodiversity, agriculture, and energy - and contributed to the refinement of the emerging narratives.



A. Frame the objectives of European policies for the region within the scope of the Alentejo Policy Lab; **B.** Deepen narratives of positive futures with Nature; **C.** Barriers and enabling measures for the implementation of policy targets; **D.** To what extent are these policy objectives relevant to the region?; **E.** What potential conflicts between these policy objectives can be identified?; **F.** What are the barriers and enabling/facilitating factors for their implementation?; **G.** Is there an opportunity to align the objectives of European biodiversity and energy policies (including those related to agriculture) through the Regional Spatial Plan (PROT)?

Figure 19. Participatory stakeholder approach in the Portuguese case

Part of exercise 1 was to ask participants to assess the feasibility of achieving three long-term objectives by 2050. Each objective was rated on a scale from 1 (not feasible) to 10 (fully feasible), with the average score and distribution shown visually (Figure 20). The exploratory exercise revealed contrasting perceptions of progress toward achieving the three potential future targets.

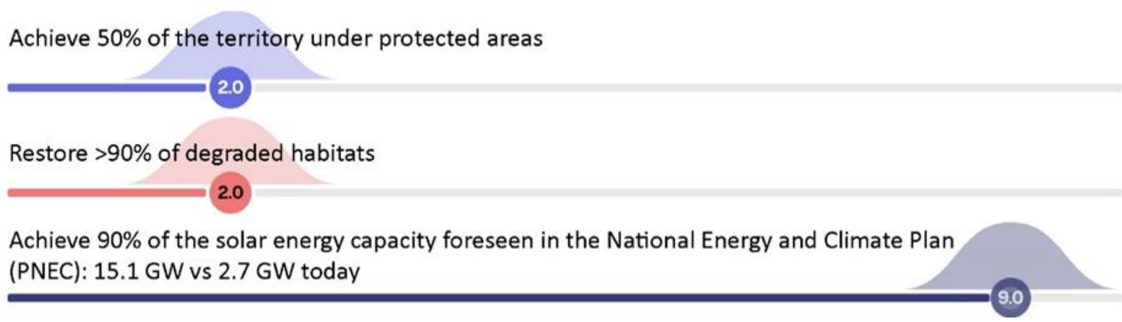


Figure 20. Exploratory target-seeking exercise on the potential future achievement of three long-term targets

Participants rated the solar energy goal with a high level of feasibility, indicating strong confidence in the ongoing expansion of renewable energy. In contrast, ecological goals such as restoring over 90% of degraded habitats and designating 50% of the territory as protected areas were both rated much lower, highlighting a perceived gap between ambitions and on-the-ground progress. These results suggest that while climate mitigation through energy transition is perceived as advancing effectively, biodiversity conservation and ecological restoration are viewed as lagging. The disparity underscores the need for stronger institutional support, integration of policy agendas, and increased visibility of conservation efforts to ensure balanced progress across sustainability domains.

Exercise 2 introduced the three NFF value perspectives by inviting participants to place votes on thematic triangles to express how each policy objective should be implemented, while exercise 3 asked participants to work in groups to evaluate draft narratives, highlighting in green the elements to retain and in red those needing revision, while also contributing written suggestions to propose improvements based on regional values and priorities.

For all three objectives—habitat restoration, sustainable farming, and renewable energy—participants generally agreed with the Nature for Nature, Nature as Culture, and Nature for Society narratives, marking many elements in green as valuable. Red-marked concerns varied: under Nature for Nature, the definition of “restoration” was seen as unclear; under Nature as Culture, the expansion of protected areas and the phrase “energy landscapes” were questioned; and under Nature for Society, reliance on ecosystem services and terms like “strictly forbidden” were flagged. Suggestions across the columns emphasized practical and context-based improvements, including local nurseries for native plants, reforesting low-quality soils, preserving watercourses, and maintaining traditional farming systems linked to biodiversity.

Following this initial workshop, a second engagement moment occurred in June 2025 through a meeting with the land-use planning unit of the regional territorial planning authority (CCDR-Alentejo). The CCDR team offered key insights into multi-level governance, local implementation constraints, and alignment with instruments such as the Regional Territorial Planning Program (PROT). It was highlighted that while the policy goals are generally relevant to the region, their practical implementation depends on:

- Clarifying the articulation between EU, national, and regional scales;
- Engaging municipalities in the identification of context-specific critical areas and conflicts;
- Promoting inter-CCDR cooperation, as exemplified by the recent alignment between the Centre and North regions during the PROT review process.
  In terms of potential policy conflicts, CCDR identified the need for further territorial diagnostics, while acknowledging emerging tensions between land-use planning and agricultural interests. As an example, in Alvito (South Alentejo), a proposed 500 m buffer zone around villages to limit intensive agriculture was met with resistance from farmers due to the anticipated loss of productive area and income).

A third collaborative event, focused on identifying barriers and enabling conditions for NFF implementation, is planned for late 2025. Initially scheduled as part of the first workshop, this participatory exercise was postponed, allowing for deeper engagement and broader inclusion of stakeholder groups.

2.6 Switzerland

2.6.1 General context

The Swiss case focuses on modelling mountainous land-use change processes, among which are deglaciation, biome shifts, and the construction of renewable energy infrastructure. Because Swiss land-use scenarios have already been established by recent research projects, the Swiss case was not part of the work for this deliverable. Sections 2.6.3 and 2.6.4 describe previous work and not original research needed for the following work in WP4. The novel contribution in the context of MOSAIC lies in the biophysical refinement of an existing model as described in section 2.6.2 which will allow to do the actual modelling needed in the following tasks.

2.6.2 Modelling methods

In order to more accurately resolve the climate change impacts on land-use options in mountain areas, an existing statistical land-use change model (Black et al., 2023, 2024) to be named evoland-plus) will be coupled to process-based biophysical models. Specifically, these are the hydrological model PCR-GLOBWB (Janzing et al., 2024; Sutanudjaja et al., 2018) and the forestry model ForClim (Mina et al., 2017). Figure 21 illustrates the integration of these biophysical models into the statistical land-use change model. Together with land-use specific ecosystem service (ES) models, the integration of biophysical process-based knowledge provides a deeper insight into the dynamics of land use and climate change.

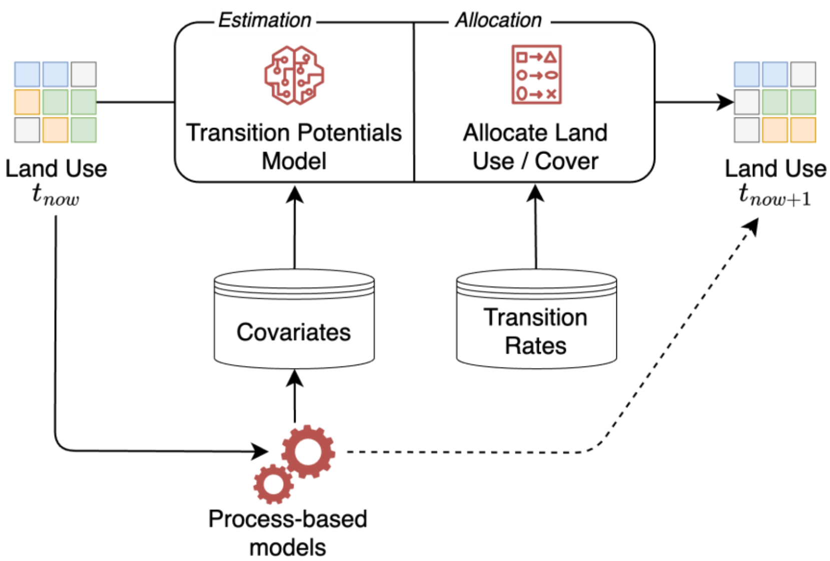


Figure 21. Illustration of the *evoland-plus* model enhancement, with process-based models affecting future land use indirectly via statistical covariates, or directly where natural processes take precedence over land-use decisions (e.g. deglaciation).

2.6.3 Exploratory scenarios

Existing parametrizations will be used covering the SSPs/RCPs combinations to drive a biophysically refined land-use model. Building on previous work by (Black et al., 2024; Mayer et al., 2023; NCCS, n.d.), the Swiss exploratory scenarios profit from two previous participatory processes eliciting expert opinions on conceivable futures of land use. SSP1, 3, 4, and 5 are covered by the National Centre for Climate Services' (NCCS) Switzerland-specific SSP-CH scenarios. SSP2 ("Middle of the Road)" was omitted from these scenarios to avoid anchoring bias in policy makers, i.e., interpretation of SSP2 as business as usual. However, as there is a legitimate interest in representing SSP2, the business-as-usual assumptions from Black et al. (2024) are used. These scenario assumptions are compatible, as they are expressed in the same land-use modelling environment. They are detailed in Table 13. The scenarios are formulated in such a way as to be independent of any projected climate change.

The SSPs will be combined with CMIP6 derived CHELSA (Climatologies at high resolution for the earth's land surface areas) downscaling climate projections (Karger et al., 2023) to be used as covariates in the land-use change model.

Table 13. Swiss Exploratory Scenario Assumptions

SSPs Description based on Riahi et al., (2017)	**Swiss LULCC Scenario Operationalisation**
SSP1 Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation)	A sustained green growth increases GDP by 60% and the population by 23% (11m) until the end of the century. Intensive agriculture, permanent crops, bushland, and alpine meadows decrease in area, while lowland grassland, forests, and urban areas expand.
SSP2 Middle of the Road (Medium challenges to mitigation and adaptation)	*Operationalisation from* business-as-usual (BAU) *in Black et al.,* (2024). A sustained economic growth increases GDP by around 60% by 2060. This is paired with a population growth to 10.5m by 2060. Urban and infrastructure expansion continue at extrapolated rates, combined with a loss of agricultural loss and open forests. The latter tend to grow into old, closed forests.
SSP3 Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation)	The weak political integration of Switzerland into an increasingly hostile world leads to increased defence spending and a weakened economy, leading to a reduction in GDP of -25% at the end of the century. The population starts to decrease after 2050, ending at -18% by the end of the century. A marked increase in forest cover is assumed. Grasslands and meadows are assumed to be substituted by intensive arable land and permanent crops, or shrubland on unsuited areas. This is the only scenario with decreasing urban areas.
SSP4 Inequality – A Road Divided	An increasing economic divide splits Swiss society into an affluent, internationally networked elite, and a

(Low challenges to mitigation, high challenges to adaptation)	disenfranchised and growing lower class. While this pathway sees GDP increasing by 40% until the middle of the century, economic degrowth sets in, leading to a 32% higher GDP in 2100 compared to today. The population development mirrors this economic development, with an initial growth to 10.3m receding to 9.5m at the end of the century. This scenario contains agricultural land abandonment and modest urban expansion.
SSP5 Fossil-fuelled Development – Taking the Highway (High challenges to mitigation, low challenges to adaptation)	A fossil resource intensive economy grows substantially until the mid-century, achieving 53% growth by 2060 – after which increasing prices for fossil resources lead to a recession, netting a growth of 27% at the end of the century. The initial economic boom leads to the greatest increase in population of any scenario, almost reaching 12m, or 32% growth, in 2060. In 2100, the population has been reduced to 10.3m. This scenario sees a significant increase in intensive agricultural areas, urban expansion, and infrastructure. Reductions in forest area, extensive agriculture, and shrubland enable these expansions.

2.6.4 Target-seeking scenarios

For the Swiss case, NFF-based nature-positive scenarios were developed in the context of Mayer et al., (2023) and implemented in the statistical land-use change model (Black et al., 2024). The refined land-use change model and the associated exploratory scenarios (see section 2.6.3) will be run under the three scenarios based on the normative perspectives of Nature for Nature, Nature for Society, and Nature as Culture. They have been operationalized with an emphasis on Swiss regional nature parks yet applied to the entire country.

The scenarios were created in a participatory process, consisting of two workshops, a questionnaire, an inductive coding stage, and a final expert review of the outcome. The first workshop used envisioning techniques with 57 participants in 11 sessions to determine nature-positive futures. These workshops all related to specific regional parks, as is illustrated in Figure 22. The second workshop called on 11 experts in a Three-Horizon approach[11] (Sharpe et al., 2016) to identify the status quo of the Ecological Infrastructure (EI) of Switzerland (horizon 1), its desired future state (horizon 3), and the actions needed to achieve the desired state (horizon 2). The same 11 experts responded to an online questionnaire to rank drivers of EI development, organized by “biophysical, socioeconomic, cultural, and political–administrative domains” (Mayer et al., 2023, p. 5).

Mayer et al. (2023) then inductively coded scenario narratives from the workshop outcomes and operationalized them in terms of the drivers identified for the questionnaire, attaching them to existing SSPs/RCPs combinations. The three scenarios constructed in this way were,

[11] The three horizons approach provides a strategic framework to simultaneously sustain current operations, manage transitional innovations, and cultivate disruptive, long-term change to drive systemic transformation.

in a last step, verified by the experts employed for the Three-Horizon workshop and the questionnaire. The land-use-specific technical implementation of the scenarios developed by Black et al. (2024) forms the basis for the analyses that will be carried out in MOSAIC. A summary of the scenario assumptions, based on Mayer et al. (2023) is given in Table 14.

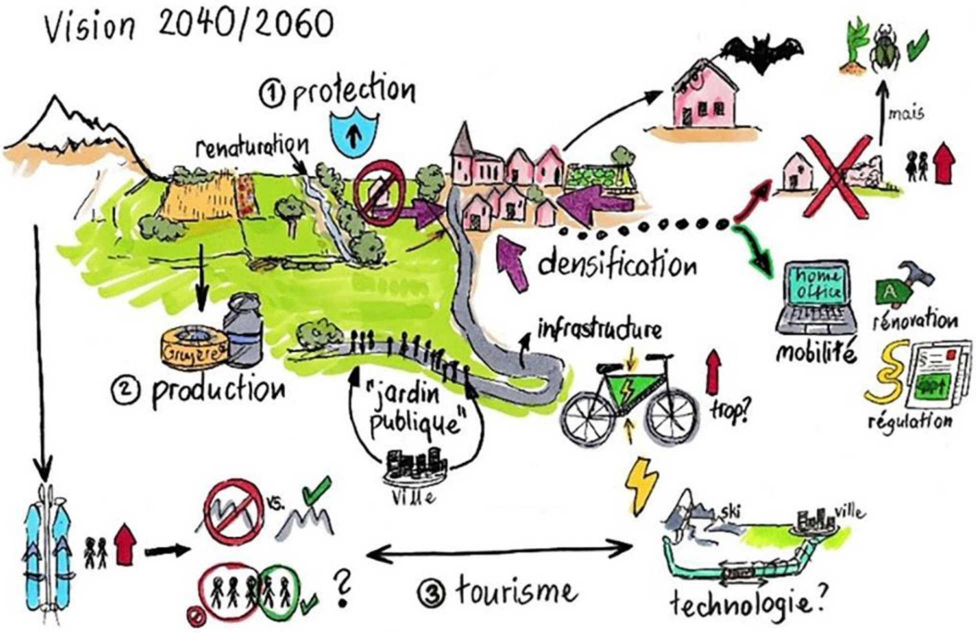


Figure 22. Reproduction of Fig. 3 from Mayer et al. (2023) depicting a “Cutout from a vision developed in a workshop with stakeholders in the Parc naturel régional Gruyère Pays-d'Enhaut”, one of four regional nature parks in the collaboration.

Table 14. NFF scenario assumptions for the Swiss case.

Nature For Nature	Nature As Culture	Nature For Society
SSP1-RCP2.6	SSP1-RCP2.6	SSP2-RCP4.5
The population grows by 6% to 9.5 million in 2060, and the economy shifts beyond the growth paradigm through sufficiency.	The population grows to 9.5 million by 2060, and the economy shifts beyond the growth paradigm through increasingly regionalized value chains.	The population grows to 10.5 million by 2060, with a strong urbanization trend. The economy experiences a green growth through increased efficiency and technological solutions.
A high value is placed on the intrinsic value of biodiversity; this is expressed in a biodiversity-oriented agricultural policy. Settlement growth is strongly limited, habitat fragmentation stymied, and	A high value is placed on the material and immaterial benefits of biodiversity. This is expressed in a productivity and biodiversity-oriented agricultural policy. Settlement growth is	A high value is placed on the material value of biodiversity, with a focus on efficient resource usage. The agricultural policy is productivity oriented. A functional zoning of the landscape leads to a spatial segregation of residential, agricultural, biodiversity, recreational, and energy

land is set aside for expanded protected areas. 30% of Swiss land is protected by 2060.	moderate, with additional land being set aside for expanded protected areas. 25% of Swiss land is protected by 2060.	production functions. Switzerland's protected areas grow to 22% of the country's surface by 2060.

2.6.5 Participatory stakeholder approach

The participatory methods that evoked the scenarios in sections 2.6.3 and 2.6.4 provide a robust basis for future analyses. For the specific case of land-use change in support of renewable energy infrastructure, participatory methods being employed for the SELINA Horizon project (SELINA Consortium, 2022) may in the future be used to augment the scenarios employed for MOSAIC in the Swiss mountainous land-use case. Moreover, the experimental setup described in section 2.6.2 is designed to be performant enough to perform substantial sensitivity analyses. This allows for future experimental setups where study participants can directly react to reparameterizations of the model. Namely, this will be employed in a qualitative narrative building exercise, where the model is interactively consulted whilst deliberating possible land-use change trajectories in the 21st century.

3 Discussion

The development of the MOSAIC scenarios is grounded in a comprehensive review of relevant land-use policies across the case studies and informed by iterative consultations with stakeholders through the Policy Labs (PLs). The scenario framework adopts a combined normative and exploratory approach that is co-created with stakeholders to ensure alignment with both EU-level policies and regional planning priorities. The exploratory scenarios in MOSAIC are based on established international scenario frameworks such as the IPCC RCPs and SSPs and allow assessment of the feasibility of achieving policy objectives under alternative socio-economic and climate change futures. In addition, normative scenarios focus on achieving policy objectives across key land system sectors, drawing on both documented policy goals and insights gained directly from stakeholder engagement in each case study. Normative policy scenarios further integrate the Nature Futures Framework (NFF), enabling the explicit representation of environmental ethics through different value perspective in the outlined pathway narratives.

The following sections discuss some of the issues and striking differences among the case studies and the work with the different policy labs tied to these case studies encountered along the process of developing these scenarios.

3.1 Translating policy targets into pathways reveals tensions between competing land demands

European environmental policy objectives cluster around themes such as food security, habitat restoration, renewable energy or climate change mitigation. Translating these into land-use pathways at the regional scale inevitably reveals tensions between competing land demands and policy sectors. MOSAIC pathway narratives show that the competition between land use and sectors differs across case study regions. For instance, setting aside agricultural land for afforestation to boost biodiversity, carbon storage and water-quality goals under Denmark's Tripartite Agreement reduces areas available for food and timber production. In Portugal's Alentejo, large-scale solar farms— a relevant contribution to meet the renewable energy target—can impinge on agricultural land, *Montado* agrosilvopastoral systems and biodiversity hotspots. Likewise, in the Flemish Ardennes, strong grassland conservation ambitions (under Natura 2000 and regional Masterplan mandates) clash with farm-level imperatives for food security and income. In the Swiss case, the central conflict is between agricultural policies that emphasize either biodiversity or productivity (Black et al., 2024). In Hungary's Sand Ridge region, severe water scarcity forces a trade-off between using land for nature-based water retention, wetland restoration, and maintaining drained, intensively farmed fields, exemplifying challenges for EU water and biodiversity policies.

3.2 Utilization of NFF shows that actions and measures depend on value perspectives

Furthermore, most land-use-related policy objectives lack spatially explicit prescriptions for implementation at the regional scale, compelling modelers to make assumptions about where, how and at what scale these interventions are to be implemented. The NFF has been operationalized in the European case to identify a set of actions and measures to reach EU Policy targets and to describe three distinct pathways that are internally consistent, but differ in the way human relationships to nature are expressed; Nature for Nature (intrinsic values), Nature for Society (instrumental values), Nature as Culture (relational values). The regional cases draw on these pathways and create target-seeking scenarios for their individual study regions, highlighting how differing value lenses yield distinct actions - even under similar policy umbrellas- and underscores the importance of refining these policy pathways through regional stakeholder input.

For example, while the Tripartite Agreement in the Danish case prescribes 140.000 ha of peatland restoration and 250.000 ha of afforestation, these aggregate indicators are not associated with specific areas. It is also unclear how to balance restoration with ongoing food and timber production and the constraints of the Water Framework Directive. By applying the NFF, the Danish afforestation trajectories were partitioned into: (i) contiguous forest cores designed for maximum biodiversity gain (Nature for Nature); (ii) peri-urban recreational and groundwater-protection plantations (Nature as Culture); and (iii) optimally sited, cost-effective carbon-sequestration forests (Nature for Society). Another example are the habitat restoration narratives in Portugal's Alentejo region, where strictly protected conservation cores are embedded within broader green infrastructure that include *Montado* agrosilvopastoral mosaics and multifunctional agrivoltaic landscapes, reflect a different NFF pathway for the biodiversity cluster. The Belgian "Farming Despite Nature" storyline predominantly embodies the instrumental "Nature for Society" orientation. This emphasises grassland productivity, but also explores impacts of other ecosystem services, biodiversity, and landscape values while intrinsic and relational values are considered in the broader analysis, even while they are not the central focus in the Belgian case. Nevertheless, balancing CAP subsidies against strict grassland-conservation targets—poses both normative and technical challenges. The Swiss scenarios are consciously kept apart from specific current or planned policies. This is because there is little sense in anticipating individual policies until 2100 unless they are part of a wider strategy; for instance, the Swiss Biodiversity Strategy (SBS) (BAFU, 2012) currently extends as a concrete Plan of Action to 2030 (BAFU, 2024a), while the national Energy Strategy 2050 (ES2050) only reaches two decades further. Nonetheless, Switzerland is party to some of the same agreements that EU member states have committed to, e.g. the KM-GBF and the SDGs, and is in theory beholden to those goals.

3.3 Ensuring stakeholder ownership of scenarios

Recognition that constructed normative narratives risk remaining purely conceptual has prompted the integration of participatory research to validate, refine and legitimate scenario outputs. Particularly for scenarios that capture peoples' values, stakeholder engagement is a prerequisite for effective policy adoption and stakeholder ownership of the scenarios (Van Vliet et al. 2010; Ried 2008). Accordingly, workshops were held in sequential Policy Labs in each case study region. In Denmark, a December 2024 workshop convened water management and forestry authorities to delineate afforestation domains, synchronise scenario timelines with parliamentary decision cycles and reconcile statutory mandates with local management protocols. Portugal's May 2025 Policy Lab employed participatory mapping and multi-criteria ranking exercises to allocate EU restoration and renewables targets across the regional landscape, thus yielding scenario levers that directly inform regional planning processes. A subsequent engagement meeting with the land-use planning unit of the regional territorial planning authority (CCDR-Alentejo) provided key insights into multi-level governance, local implementation barriers, and alignment with instruments such as the Regional Territorial Planning Program (PROT). Belgian workshops staged between September 2024 and June 2025 systematically elicited farm-level data on grassland management, aligned scenario templates with evolving EU, Flemish and local biodiversity policies, and secured stakeholder endorsement of the “Farming Despite Nature” narrative, thereby cementing both credibility and ownership.

3.4 Multi-scale and inter-regional model coupling

The scenarios presented here will be used in MOSAIC to further develop the advanced land-use models within the case studies and to couple these across spatial scales. The models will now be parameterized with the empirical data derived from WP3 (T3.1 and T3.3). While all modelling groups have agreed to focus on the same combination of SSPs/RCPs elements and thus share the same main assumptions on scenario drivers, some challenges regarding the inter-linkage of exploratory scenarios across scales arise from case-specific modelling requirements. For instance, the level to which CRAFTY-Europe and PLUMv2 provide boundary conditions to regional/local scale models differs, with stricter model linkage between CRAFTY-Europe (incl. the modelling for the Hungarian case) and the models used in the Portuguese and Belgian cases, compared to the models of the Swiss and Danish cases. Additionally, current model capabilities in the Danish case may not allow for the inclusion of climate projections, leading to differences in how scenario elements are linked across spatial scales and cases.

Further, while the evaluation and co-creation of target-seeking (policy) scenarios in the policy labs strengthen the relevance of the developed scenarios for stakeholders, it might also pose a challenge to the comparability of modelling outputs across cases. For instance, stakeholders across the policy labs will identify different EU policy targets to be of relevance to their respective cases. While comparability in terms of the selected targets might thus be limited, utilising the NFF allows to link case-specific target-seeking scenarios by their underlying normative stance, i.e., their underlying value perspective on human-nature relationships (Pereira et al., 2020).

In summary, the MOSAIC scenario approach allows for context-specific scenarios to be co-developed with stakeholders and interlinked across regions with an EU-wide modelling application. The developed scenarios will allow the MOSAIC modelling teams to simulate well-known SSPs/RCPs scenarios, but also to model pathways towards a nature-positive land system in Europe.

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