

PLUS CHANGE

PLANNING LAND USE STRATEGIES: MEETING BIODIVERSITY, CLIMATE AND SOCIAL OBJECTIVES IN A CHANGING WORLD

D3.5 – LAND SYSTEMS MAPS OF SPATIALLY EXPLICIT LAND USE SCENARIOS

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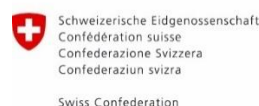


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List of Abbreviations

Term	Description
CLUMondo	Conversion of Land Use on Mondial Scale
CLD	Causal Loop Diagram
PL	Possible Landscapes
GLOBIOM	Global Biosphere Management Model
CAPRI	Common Agricultural Policy Regional Impacts
SSP	Shared Socioeconomic Pathway



Executive Summary

This Deliverable is part of Task 3.4 “Modelling land use change scenarios from different levels” within Work Package 3 “Future Sustainable Land Use Strategies” of the PLUS Change project. Its main objective is to translate the qualitative scenarios developed in previous tasks into spatially explicit land system maps for Europe in 2050, thereby operationalising visions and policy trends into model-based futures.

Building on Deliverable 3.4, which synthesised local vision from the Possible Landscapes workshops and policy-driven pathways derived from causal loop diagrams (CLDs), this deliverable provides the spatial modelling layer. The qualitative scenario narratives were clustered into two main groups of practice cases: (1) Zaanstreek-Waterland (NL), Île-de-France (FR), 3 Countries Park (DE/NL/BE), Flanders (BE), and Surrey (UK) and (2) Parc Ela (CH), Green Karst (SI) and Lucca (IT). For each cluster, two (contrasting) scenarios were modelled with the land system change model CLUMondo:

- Policy trend scenarios: Fragmentation (cluster 1) and Touristification (cluster 2)
- Possible Landscapes scenarios: Rewilding (cluster 1) and Reactivating (cluster 2)

CLUMondo allocates land systems based on three main interacting factors: societal demand, location suitability and conversion rules. Country-level simulations were carried out at 1x1km resolution for the period 2020-2050.

The resulting maps reveal distinct scenario trajectories. Policy trend scenarios generally show continued intensification of agriculture and forestry, loss of heterogeneous mosaics, and expansion of urban land, with variations across countries. By contrast, Possible Landscapes scenarios shift toward extensification and more heterogeneous landscapes, favouring mosaics, lower-intensity agriculture, and ecological restoration, again with variations across countries. Settlement growth is more constrained in the Possible Landscapes scenario.

These land system maps represent an important bridge between qualitative visions and quantitative assessments. They form the foundation for next analyses in PLUS Change, for example human well-being indicators will be assessed on top of these maps. They also provide a reference for WP4, where impacts of behavioural changes on land systems will be studied.

This exercise also has methodological challenges. Translating the stakeholder visions and policy trend scenarios into quantitative model inputs requires simplification. An example is regenerative or multifunctional farming practices that do not fit within the classical land system classes. Nevertheless, this deliverable provides a set of European-scale, spatially explicit scenario maps, making it possible to compare alternative futures.



Content alignment with other PLUS Change deliverables

Input	Output
<p>D3.1 Representations of Possible Landscapes in the Practice Cases</p> <p>D3.2 Policy drivers of Land Use Change</p> <p>D3.3 Handbook on developing integrated scenarios to explore sustainable land use strategies</p> <p>D3.4 Descriptive land use scenarios for European Regions</p>	<p>D3.6 Simulated spatial land use strategies for 2050</p> <p>D4.3 Reports on the impacts of behaviour changes on biodiversity, climate and well-being indicators</p>
	<p>Milestone 5 - Land systems maps</p>



1 Introduction

1.1 Purpose & Scope

The PLUS Change project aims to create land use strategies and decision-making processes that meet climate, biodiversity and human well-being objectives. The 12 practice cases in PLUS Change are the real-world examples, in which these processes are further investigated to eventually drive transformative change towards a sustainable world.

This deliverable primarily builds on Deliverable 3.4, in which the University of Ljubljana harmonised two inputs into integrated scenarios for all Practice Cases. Deliverable 3.4 used the Possible Landscapes (PL) workshop visions and the policy analysis captured in the Causal Loop Diagrams (CLDs).

The content of these two inputs is available in the following documents:

- For explanations and narratives of individual Possible landscapes scenarios visit the dedicated website [Possible landscapes](#)
- For explanation of policy trends and land use dynamics through causal loop diagrams, see [Deliverable 3.2 Policy drivers of land use change](#)
- For discussion of past land use changes within the practice cases see [Deliverable 2.2 Narratives of determinants of land use change and their diversity across Europe](#)

In this deliverable, the narrative clustered scenarios are translated into spatially, explicit modelling assumptions to model future land system changes: we move from words to maps. In this way, the rich qualitative material generated so far can be assessed in new ways. It is an operationalisation of visions, since it quantifies the composition of croplands, forest, settlements that a storyline requests and where these changes are most likely to occur. This allows us to test whether locally desired futures (PL) are physically feasible once aggregated to regional and European scales. The future land system maps of 2050 also provide the starting point for impact assessment of the scenarios: it is the spatial canvas on which biodiversity, ecosystem services and well-being indicators will be overlaid, to compare trade-offs and synergies across scenarios and practice cases.

1.2 Document Structure

The document is organised as follows:

Section 1 - Introduction

Section 2 – Methodology

Section 3 – Results

Section 4 – Discussion and Conclusions



2 Methodology

2.1 Overview

The harmonised scenario narratives of Deliverable 3.4 are used as a starting point. The descriptions in Deliverable 3.4 are created for clusters, instead of each separate Practice Case. These clusters are based on an identification of common patterns on surface and latent level (Neuendorf et al., 2017). For Possible Landscapes this was done by examining (1) which land use changes into another and to what extent, (2) which land system dictates the management of other land systems and (3) in which direction these changes go. Furthermore, impactful driving forces, problems and hierarchical clustering analysis based on socio-geographical data. Lastly, the modelling and its analysis is significantly facilitated if the modelling clusters are spatially connected. For each cluster, land system changes are simulated for two scenarios; one scenario based on Possible Landscapes outcomes, and one scenario based on an analysis of ongoing policy drivers, the Causal Loop Diagram (CLD).

The land system modelling is done for the two main clusters shown in Figure 1 and Table 1. In terms of output, this means that for each cluster two maps were produced: one for the Possible Landscapes scenario and one for the policy scenario. These maps were compared with the base map of 2020, the starting year of the modelling.

The thematic clusters 3 and 4 are left out of the modelling, because the focus is very specific. For thematic cluster 3, the urban development focus is on a smaller scale than the land system modelling on 1km allows for. Landscape elements in urban infrastructure are not the focus of

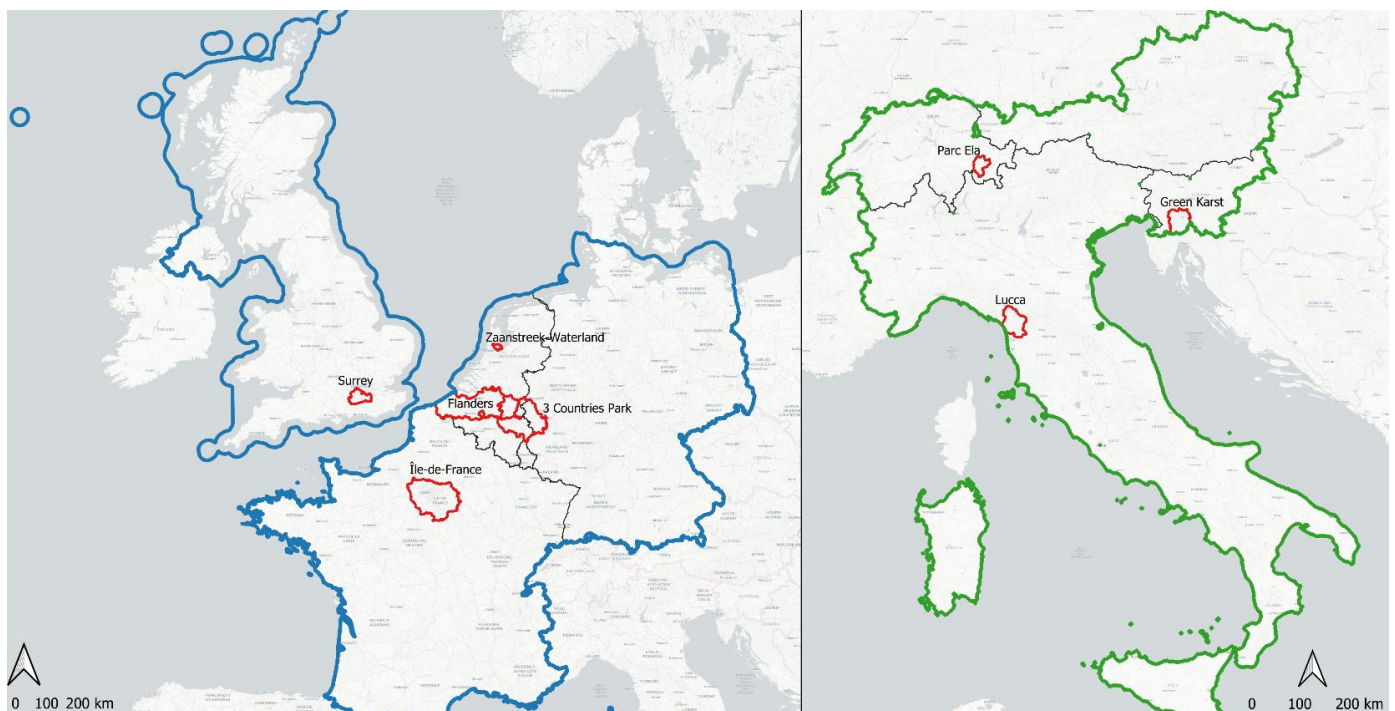


Figure 1. The two main clusters. Left figure outlined in blue: main cluster 1, consisting of the following Practice Cases (outlined with red): 3 Countries Park (BE/DE/NL), Île-de-France (FR), Flanders (BE), Surrey (UK) and Zaanstreek-Waterland (NL). Right figure outlined in green: main cluster 2, consisting of the following Practice Cases (outlined in red): Green Karst (SI), Lucca (IT) and Parc Ela (CH).



the land system modelling and therefore left out of the analysis here. Thematic cluster 4 focuses on restoration of brownfield sites. This is possible to model with land system modelling. However, the scenario has a very narrow focus, where driving forces as demography, environment and infrastructure are not discussed. The four Practice Cases included in these two thematic clusters are asked in the survey, if they could fit in one of the two main clusters based on the scenario narratives. 3 of the 4 practice cases (South Moravia, Nitra, Mazovia) identified that they relate most to the scenarios defined for main cluster 1.

Consequently, the following four scenarios are modelled with the land system change model CLUMondo: Fragmentation (Cluster 1 policy trend scenario), Touristification (Cluster 2 policy trend scenario), Rewilding (Cluster 1 possible landscapes scenario) and Reactivating (Cluster 2 possible landscapes scenario) (see Deliverable 3.4).

Table 1. Overview of upscaled scenarios. This table comes from Deliverable 3.4, but is repeated here for completeness.

Cluster	Included practice cases	Predominant topics
Main cluster 1	Amsterdam, Surrey, Île de France, 3 Countries Park, Flanders	Improving water management to adapt to floods and droughts, introducing measures to agriculture to improve soil conditions and water retention, rewilding, curbing urban sprawl
Main cluster 2	Parc Ela, Lucca, Green Karst	Maintaining vital agriculture under globalization pressures, sustainable development of tourism, increasing attractiveness for young people, adapting to climate change in challenging natural conditions (hills, mountains)
Thematic cluster 3	Nitra, Mazovia	Development of urban green infrastructure, increasing urban quality of life, directing urban developments
Thematic cluster 4	Kaigu, South Moravia	Restoration of brownfield sites

2.2 Land system modelling – CLUMondo

CLUMondo is a spatially explicit model to simulate changes in the spatial allocation of land systems (Dou et al., 2023; Van Asselen & Verburg, 2013). The model allocates land systems based on the demands for goods and services specific to the modelled region, and on location suitability and conversion rules (see Figure 2). Land system change is typically driven by a demand of ecosystem goods and services. For example, an increase in the demand for food produced in the modelled region yields an increase in cropland in that region. Each land system can produce several goods and services that contribute to fulfilling societal demands. So, one land-system type can produce several demands. For example, rural villages provide both residential space as well as agricultural production.



Demands are calculated externally (see section 2.3.2) and imposed on the region. Location suitability for different land systems is based on empirical relationships between current distribution of land systems and socio-economic and biophysical location factors. While some of these factors are expected to remain constant over time (e.g. elevation), other can change (e.g. precipitation, temperature) leading to changes in location suitability.

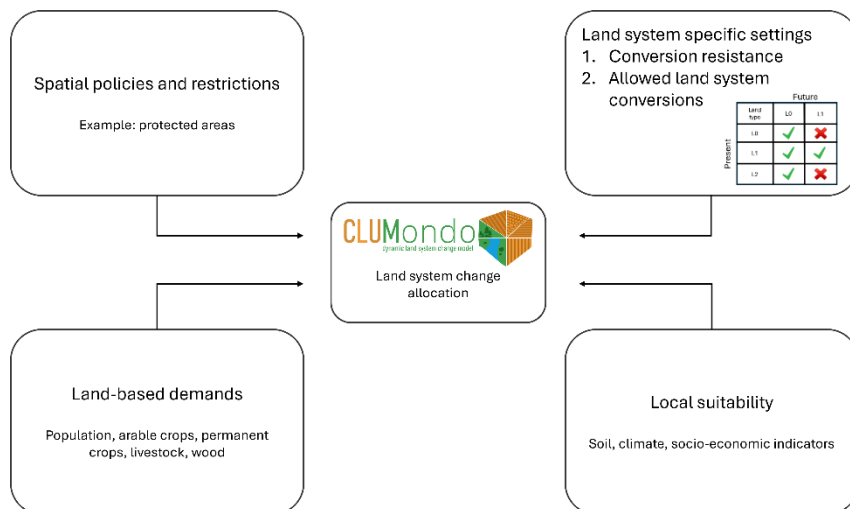


Figure 2. Overview of the modelling procedure of CLUMondo

The model operates iteratively, allocating land systems to pixels across the study region based on suitability and conversion rules. If the allocation meets the required demand for goods and services, the model advances to the next time step. For this deliverable, annual timesteps are used from 2020 to 2050.

2.2.1 Initial land system map for Europe

The baseline land system map of Europe is based on a map by Dou et al., 2021 and Sandström et al., 2023. The map consists of 18 classes and has a spatial resolution of 1x1km. To create this map, diverse indicators of land cover, land use intensity and management practices are combined. The map has a spatial resolution of 1 km and is the starting point of the modelling in the year 2020 (see Figure 3). To complete the 18 classes, two classes are considered static, so they are not part of the modelling process: (16) water bodies and (17) bare, rock and shrubs. A few of the indicators used to create this land system map are the Copernicus imperviousness index for the settlement classes, nitrogen application and mean field size for the arable cropland classes, mowing frequency and livestock units for grasslands and a dataset from Scherpenhuijzen et al., 2025 for the forest management classes. Sandström et al., 2023 contains a complete description of how the map was composed.



Land systems

- 0 - Low intensity settlement
- 1 - Medium intensity settlement
- 2 - High intensity settlement
- 3 - Wetlands
- 4 - Forest/shrub and cropland mosaic
- 5 - Forest/shrub and grassland mosaic
- 6 - Low intensity arable cropland
- 7 - Medium intensity arable cropland
- 8 - High intensity arable cropland
- 9 - Low intensity grassland
- 10 - Medium intensity grassland
- 11 - High intensity grassland
- 12 - Permanent cropland
- 13 - Primary + Close to nature forest
- 14 - Combined objective forest
- 15 - Intensive + very intensive forest

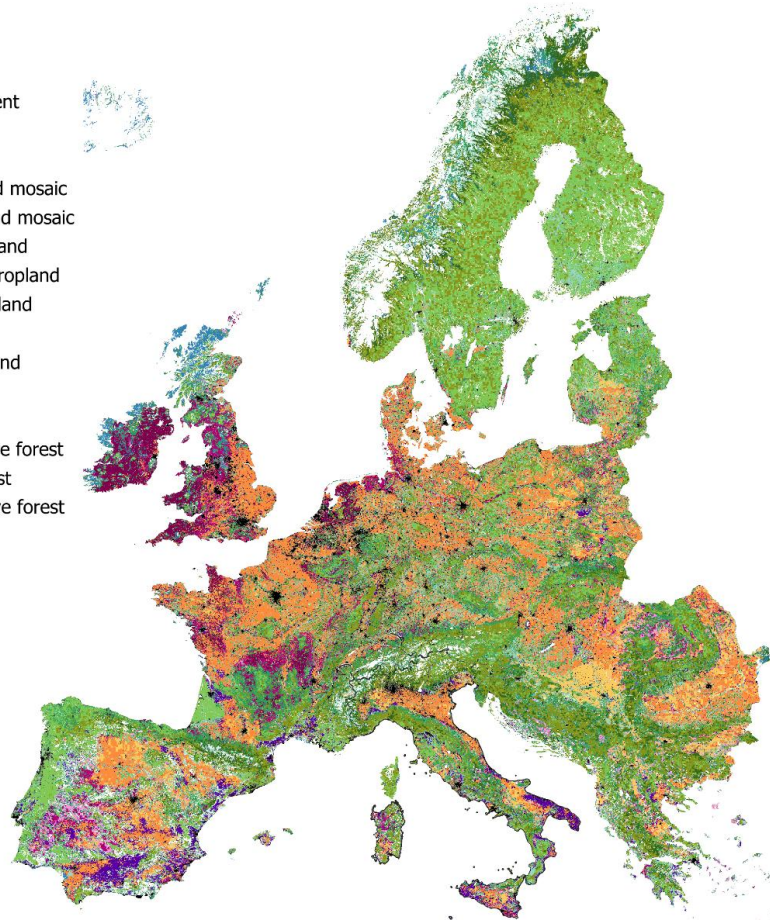


Figure 3. Initial land system map of 2020, from Sandström et al., 2023.

2.2.2 Spatial suitability

The spatial suitability of the different land systems is defined by soil characteristics, five bioclimatic variables (annual mean temperature, mean diurnal range, temperature seasonality, annual precipitation, precipitation seasonality), and socio-economic conditions (Dou et al., 2023). The 9 used soil indicators are clay content, silt content, sand content, coarse fragments, bulk density and available water capacity (AWC) (all six from Ballabio et al., 2016), pH in water and cation exchange capacity (both from Ballabio et al., 2019) and soil organic carbon content (de Brogniez et al., 2015). The socio-economic indicators are accessibility to cities (Weiss et al., 2018), motorised travel time to healthcare (Weiss et al., 2020), total road density (Meijer et al., 2018). Climate data is from Chelsa CMIP6: annual mean temperature, mean diurnal range, temperature seasonality, annual range of air temperature, annual precipitation amount, precipitation seasonality.

2.2.3 Demands

For the modelling, five baseline demands are considered: population, arable crops, permanent crops, livestock and wood. These five demands capture the bulk of society's claims on European



land. For specific scenarios, additional demands can be added. Source data for these demands are described in Section 2.3.2.

2.2.4 Productivity of each land system per demand

The modelling requires information on the average productivity of each land system for the different demands. While population is primarily associated with urban land systems, several other land systems also contribute to providing housing. Because of this reason, all land systems are overlaid with the population grid of Batista e Silva et al., 2021. The demand for arable crops is driven by the arable croplands and the forest, shrub and cropland mosaic. The productivity is calculated with a global wheat yield map from Luo et al., 2022. Livestock is driven by grassland systems and the forest, shrub and grassland mosaic. The productivity of these systems is calculated using the data on livestock presence and grazing from Malek et al., 2024. Since permanent crops are only driven by the land system permanent cropland, the productivity can be derived from CAPRI. The wood productivity is derived from the wood production intensity map of Verkerk et al., 2015.

2.2.5 Modelling at country-level

Although the Possible Landscapes and Policy scenarios are formulated for two trans-boundary main clusters in Deliverable 3.4, the productivity of land systems and the demand for goods and services vary substantially between countries. To better reflect these differences, CLUMondo was run at country scale, allowing for more realistic behaviour.

2.3 From scenarios to modelling inputs

The qualitative scenario narratives of Deliverable 3.4 are translated into operational inputs for CLUMondo. First, the conversion matrix states which land system conversions are allowed. Secondly, additional demands impose quantitative targets, such as room for recreation or improved water retention areas. Finally, location-specific preference maps adjust the relative attractiveness of individual land systems at pixel level, capturing spatial policies that, for example, prioritise wetland restoration or the establishment of ecological corridors. Together, these three mechanisms tailor the model for each scenario.

2.3.1 Complementing the scenarios with the Shared Socioeconomic Pathways

Although the Possible Landscapes and policy scenarios have rich storylines, they have limited coverage on two model-critical elements. Firstly, future demands for land-based goods and services are very hard to derive precisely from stakeholder interaction. Secondly, some specific land systems are not explicitly discussed. To address these gaps, quantitative projections from the Shared Socio-economic Pathways (SSPs) are incorporated. The SSPs are a set of global socioeconomic development scenarios that were developed in an IPCC report to facilitate climate change research and integrated assessment modelling. They describe alternative trajectories for population, economic development, consumption, technology, and environmental policy over the 21st century, and are widely used as inputs in land-use and climate models (O'Neill et al., 2017; Riahi et al., 2017)

Specifically, the Possible Landscapes scenario aligns with SSP1 (Sustainability/"Taking the green road"), because its resource-efficient production systems and ambitious ecological-



restoration targets resonate with Possible Landscapes' focus on low-input farming and strong environmental stewardship. Conversely, the policy scenarios are complemented with SSP2 ("Middle of the road"), because its pathway marked by conventional economic development resembles with the policy scenarios' incremental land-use pressures. The second gap (not all land systems covered) is filled by complementing the scenarios with the SSP scenarios, already available in CLUMondo. Thus, the bottom-up Possible Landscapes and policy scenarios are complemented with the top-down SSP scenarios.

2.3.2 Demands

Because the PL and CLD narratives do not specify quantitative demand trajectories for land-based goods and services, these were derived from established country-level integrated-assessment models. The models rely on the Shared Socioeconomic Pathways. Content analysis indicated that the Possible Landscapes scenarios most closely matches the "Sustainability" SSP 1 pathway, whereas the CLD policy scenario aligns the "Middle-of-the-Road" SSP2 pathway.

For arable crops, livestock products, timber and livestock, demand projections were taken from GLOBIOM, coupled with the AGLINK-COSIMO market module, under SSP 1 and SSP 2 assumptions (Dou et al., 2023; Havlík et al., 2011; Lauri et al., 2019). GLOBIOM is a global partial-equilibrium model with endogenous trade, which means that increases in local consumption, depending on the scenario, are either produced in the same region or are part of the global market, and do not automatically imply local land use changes.

Demand for permanent crops (e.g. orchards, vineyards) is not covered by GLOBIOM, so this was obtained from the CAPRI model (Kesting & Witzke, 2021). CAPRI provides a single baseline projection that reflects recent trends and current policies (e.g. CAP implementation). Unlike GLOBIOM, CAPRI does not have SSP-differentiated trajectories. Consequently, the same CAPRI baseline series was applied to both scenarios.

Population data is taken from the Wittgenstein Centre's SSP-specific demographic projections (KC et al., 2024).

GLOBIOM does not report country-specific results for Switzerland, or the United Kingdom, so these gaps are filled by borrowing trends from the most comparable cases: Austrian trajectories for Switzerland, and the average of the main cluster 1 countries for the United Kingdom. While these proxies approximate the agroeconomic context of a country, they inevitably miss some commodity-specific nuances, a limitation we acknowledge. As the PLUS Change project progresses, there is opportunity for the practice cases and researchers to consider the implications of the assumptions made for their land use decision making.

For the Possible Landscapes demands, the wood demand is set constant after the year 2030, instead of a steady increase according to the SSP1 wood production demand from GLOBIOM. GLOBIOM has a strong focus on the use of biofuels in SSP1, whereas this is not reflected in the Possible Landscapes storylines. Furthermore, this increase would imply a strong intensification of forests to plantation forests. This trend is not in line with the PLUS Change scenarios and therefore not adopted. An overview of the data sources of the demands and scenario-specific adaptations is provided in Table 2.



Table 2. Overview of demand sources and scenario specific adaptations used in the CLUMondo modelling.

Demand	Source	Adaptations
Population	Wittgenstein Centre (KC et al., 2024)	- PL: SSP1 - CLD: SSP2
Arable crops	GLOBIOM (Havlík et al., 2011; Lauri et al., 2019)	- PL: SSP1 - CLD: SSP2
Livestock	GLOBIOM (Havlík et al., 2011; Lauri et al., 2019)	- PL: SSP1 - CLD: SSP2
Wood production	GLOBIOM (Havlík et al., 2011; Lauri et al., 2019)	In the Possible Landscapes scenario, the SSP1 demand is set constant after 2030.
Permanent crops	CAPRI (Kesting & Witzke, 2021)	One trajectory provided, used for both PL and CLD.

2.3.3 General conversion rules

Some conversion rules in CLUMondo apply to all scenarios, so the rationale behind these rules are explained in this section:

- Settlements: built-up area is effectively irreversible. Therefore, conversions from any settlement class back to a more natural class are blocked as well as extensification of settlement area (e.g. from high- to low-density settlements). Furthermore, non-settlement land systems first convert to low- or medium-density and cannot convert directly into high-density settlements, since infrastructure cannot change that fast. Lastly, conversion to settlements is only allowed outside Natura2000 and Emerald areas, reflecting protected-area constraints.
- For permanent cropland, a minimum time of 5 years is required before permanent cropland can change into other systems, because such an investment only pays off after an estimated time of 5 years. Furthermore, it was observed that in the European landscape that permanent cropland is often co-occurring with low-density settlements, so therefore it is allowed to convert low-density settlements into permanent cropland, unlike all other transitions from settlements into other farming systems or natural systems. In this way, we try to mimic the permanent cropland behaviour better.
- Non-forest land systems cannot convert directly into primary+close-to-nature forest, since these ecosystems are only established after long times with managed afforestation. (Non-forest land systems can convert to combined-objective forestry or (very) intensive forestry and then eventually into primary+close-to-nature forest.)
- (Very) intensive forestry: this land system can only be converted into other land systems after the rotation length. This rotation length differs per region. In Western Europe, this minimum rotation length is 30 years. In Southern Europe the average felling age is lowest, with Eucalyptus plantations having a rotation length of minimum 10 years and a share of



11% (Xu et al., 2020). The proposed minimum rotation length is thus 10 years. For Eastern Europe, the rotation length is implemented with 20 years.

Next to these general conversion rules, also neighbourhood settings are applied to mimic the tendency of certain land systems to cluster. The agglomeration of high-density urban areas, high-intensity agriculture and forestry is enhanced with these settings, which means that the composition of surrounding cells contributes to the suitability of a certain location. In the next sections, some scenario specific conversion rules are discussed. In Appendix 1 the complete conversion matrices are displayed.

2.3.4 Policy scenario main cluster 1: Fragmentation

This scenario stresses intensification of agriculture and forestry, continued settlement growth, but also protection of nature. These storylines are implemented in the conversion matrix. Intensification shifts in agriculture are allowed. To protect nature, mosaics, low-intensity arable cropland and grasslands are only allowed to transition to higher intensity systems outside Natura2000 or Emerald areas.

These dynamics are taken into account when developing the conversion matrix in the following way:

- Wetlands can only convert to other systems outside Natura2000 or Emerald areas.
- Mosaics are protected and can only transition into other systems outside Natura2000 or Emerald areas.
- Close-to-nature/primary forest and combined-objective forestry can only transition into other systems outside Natura2000 or Emerald areas.
- Natural or not-high intensive agricultural systems can only transition into (very) intensive forestry outside Natura2000 or Emerald areas.
- Mosaics, low-intensity arable cropland, low-intensity grasslands and combined-objective forestry and (very) intensive forestry can convert into all classes except high-intensity urban settlements, but only outside Natura2000 and Emerald areas. This means that intensification of these systems is possible.

2.3.5 Policy scenario main cluster 2: Touristification

To operationalise the Touristification narrative, we identified that the most important land system dynamics are agricultural extensification, intensification of forestry, while protecting natural areas. This is implemented in the following way:

- Agricultural extensification is 'encouraged', but not enforced. Intensification is not prohibited, because no actual policy instrument formally bans them. However, local suitability and demand could make them unattractive through other modelling inputs, so it still matches the stagnation of agriculture in the storyline.
- The mosaics and close-to-nature/primary forest and combined-objective forestry are only allowed to convert to other systems outside of Natura-2000 area.

2.3.6 Possible Landscapes main cluster 1: Rewilding

The dominant themes in the Rewilding scenario are extensification of agriculture, urban densification and limiting urban sprawl and connecting natural areas. There is also a strong



focus on flood risk and droughts, which is implemented partly with wetland restoration. These themes are implemented in the following ways:

- Like in the policy scenarios, conversion to settlements is only allowed outside nature-protected areas. To mimic urban densification, when meeting population demands, high-intensity urban settlements will be pushed first, so that first existing settlements are intensified, before expanding urban area.
- Intensification of agricultural classes are prohibited. The agricultural extensification in the Possible Landscapes scenarios comes from an exploratory nature (unlike the policy scenarios), and is therefore implemented.
- The connectivity of natural areas is implemented using additional local preferences for certain pixels. This is done by combining the Natura2000 and Emerald areas with a dataset of Dertien, 2025 on corridors/connectivity for large mammals. For each modified land system in this new priority natural connectivity map, preference is added to convert to mosaics or primary+close-to-nature forests.
- Wetland restoration is implemented in the scenario using the location preferences for wetlands based on a dataset of Jung, 2025. This dataset contains a categorical raster with for each pixels the most likely current potential natural vegetation (PNV). One of the categories is wetlands. Pixels, where this data value of wetlands overlaps with current agricultural systems of the land system map, are given an increased probability to convert to wetlands.

2.3.7 Possible Landscapes main cluster 2: Reactivating

The Reactivating pathway emphasises on keeping agriculture where it is, bringing recently abandoned land back to productive use and improving landscape functions (water retention, biodiversity and recreation). In terms of land systems, this means keeping most already existing arable and grassland systems, but favouring lower-intensity variants and especially pushing toward the mosaic classes. This emphasis on mosaics fits the Reactivating storyline, because mosaics are the spatial expression of multifunctional, diversified farming: they bundle small fields and natural elements in one pixel. This configuration reflects what is described in the narrative. By steering marginal areas towards mosaics, the model operationalises the narratives of this scenario.

Furthermore, settlement policy favours densification over sprawl. The conversion matrix further contains the following conversion rules:

- Wetland restoration: here the same implementation is used as in the Rewilding scenario. So, most rural classes can convert into wetlands, while wetlands themselves cannot convert to other classes.
- Connectivity of natural areas: same implementation as in the Rewilding scenario with additional local preferences.
- Agriculture: intensification of agricultural systems is prohibited.
- Stable forest extent: close-to-nature/primary forest is protected, since it is not allowed to convert this system to other systems.



3 Future land systems maps

This chapter presents the 1x1km maps modelled with CLUMondo for all four scenarios. It discusses the main spatial-temporal patterns that emerge between the 2020 baseline and the 2050 horizon. Each subsection first highlights the pan-cluster signal and then unpacks some country-specific nuances.

3.1 Policy scenario cluster 1: Fragmentation

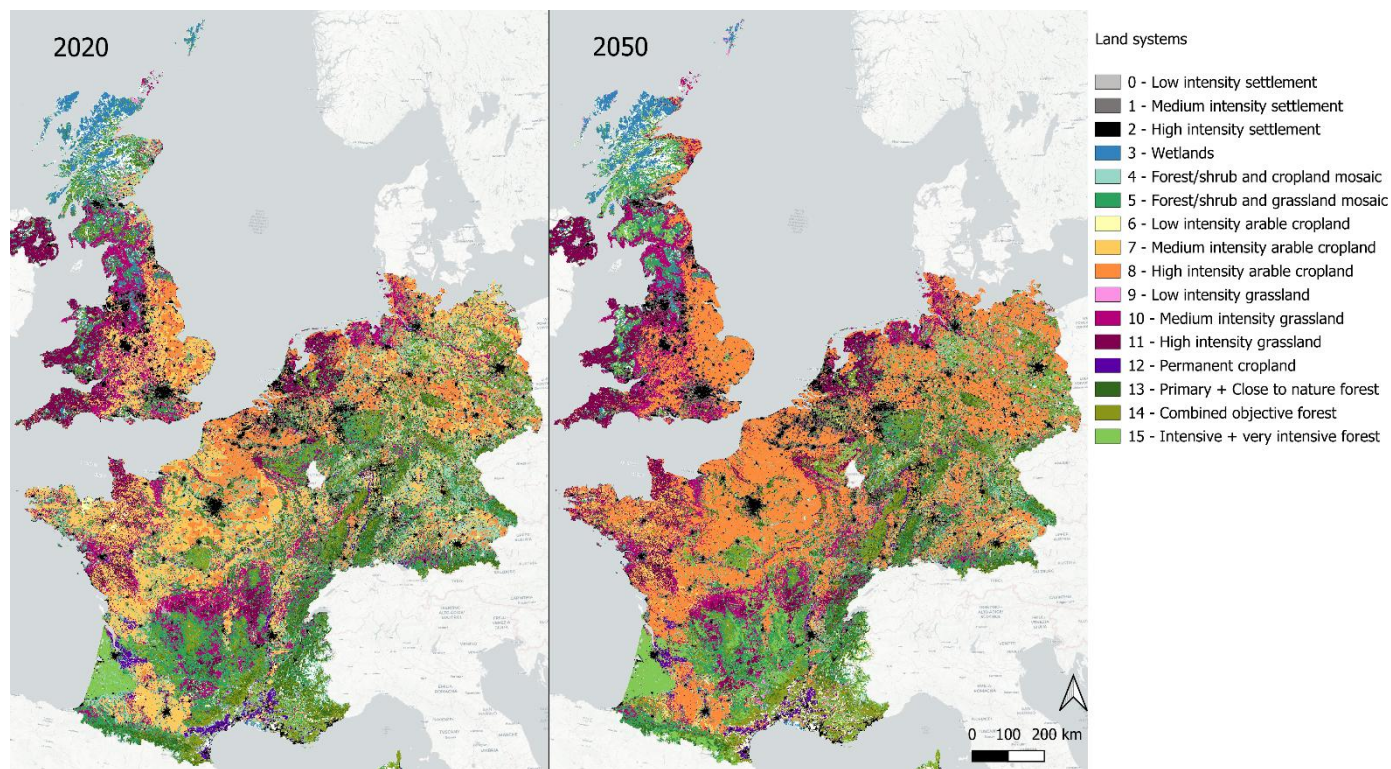


Figure 4. Maps of land systems in year 2020 and year 2050 with the policy scenario Fragmentation of the cluster with Practice Cases Zaanstreek-Waterland (NL), 3 Countries Park (BE/NL/DE), Flanders (BE), Île-de-France (FR) and Surrey (UK).

Across cluster 1, the policy scenario Fragmentation steers land systems toward considerably high-intensity systems, while leaving the total extent of the broad land system classes largely intact, with an exception of the declining mosaics (see Figure 13) losing ground to specialised arable and grassland systems. This intensification of arable cropland is clearly visible in the western France, England and Germany. The intensification of forestry is clearly visible in the Massif Central in France. The Netherlands is an outlier here, because it is already dominated by high-intensive farming systems, so it shows little change, because the baseline is already almost entirely high-intensity.



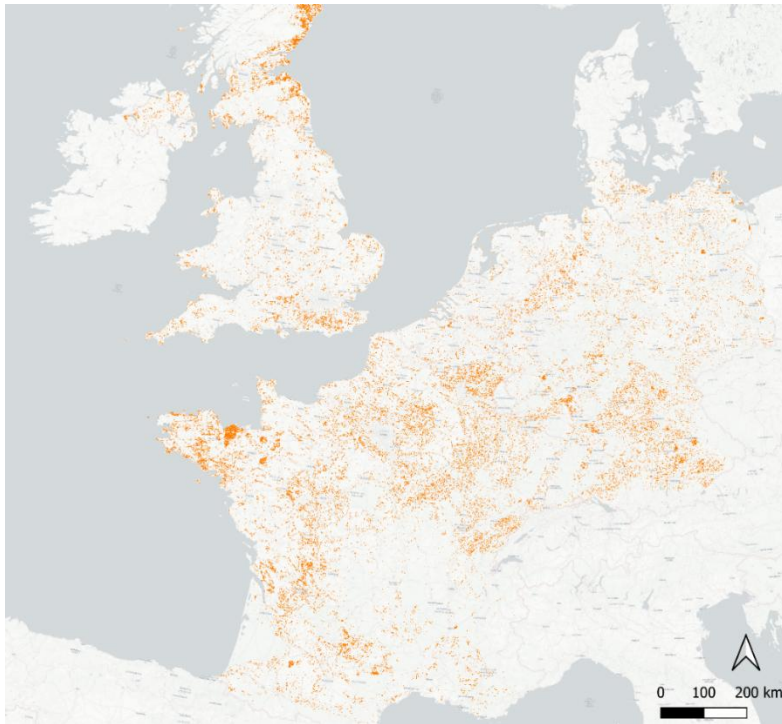


Figure 5. Hotspot map of agricultural intensification in CLD scenario. Pixels that are agricultural systems in 2020 and transition to higher-intensity agricultural systems in 2050 are displayed in orange.

All countries exhibit a pronounced conversion of medium-intensity arable cropland into high-intensity arable cropland (see Figure 6 for France). A parallel intensification occurs with the grasslands, although less strong. Figure 5 shows the areas where already existing agricultural systems in Cluster 1 intensify. Forest area remains broadly stable, but forest management intensifies. Combined-objective and primary forestry declines, of which a large share converts into very (intensive) forestry (see Figure 7 for the United Kingdom). This trend is strongest in Belgium and France, moderate in Germany and visible but minor in the Netherlands. The heterogeneous mosaic classes shrink sharply in every country. Urban and peri-urban land grows, but the magnitude varies. Summarised, the policy scenario internalises productivity goals by pushing arable and pastoral systems toward higher productivity.

- Belgium almost eliminates its medium-intensity classes, shifting to high-intensity farming and (very) intensive forestry. Strong decrease of mosaics, there was a large area of forest, shrub and grasslands, but this is almost gone, forest, shrub and cropland mosaic is more intact. Medium- and high-intensity settlements increase.
- Germany follows a similar trajectory but with milder magnitudes and stable settlement area.
- France gains a small amount of arable cropland and intensifies a large share of its forest and grassland and loses most of its forest, shrub and cropland mosaic to arable croplands.
- The Netherlands is already at the top of high-input farming, so changes are minimal.



Both mosaic classes erode (visible in northeastern Slovenia in Figure 8), but the magnitude is smaller than in cluster 1. The aggregated trends of the classes in Cluster 2 are visualised in Figure 14.

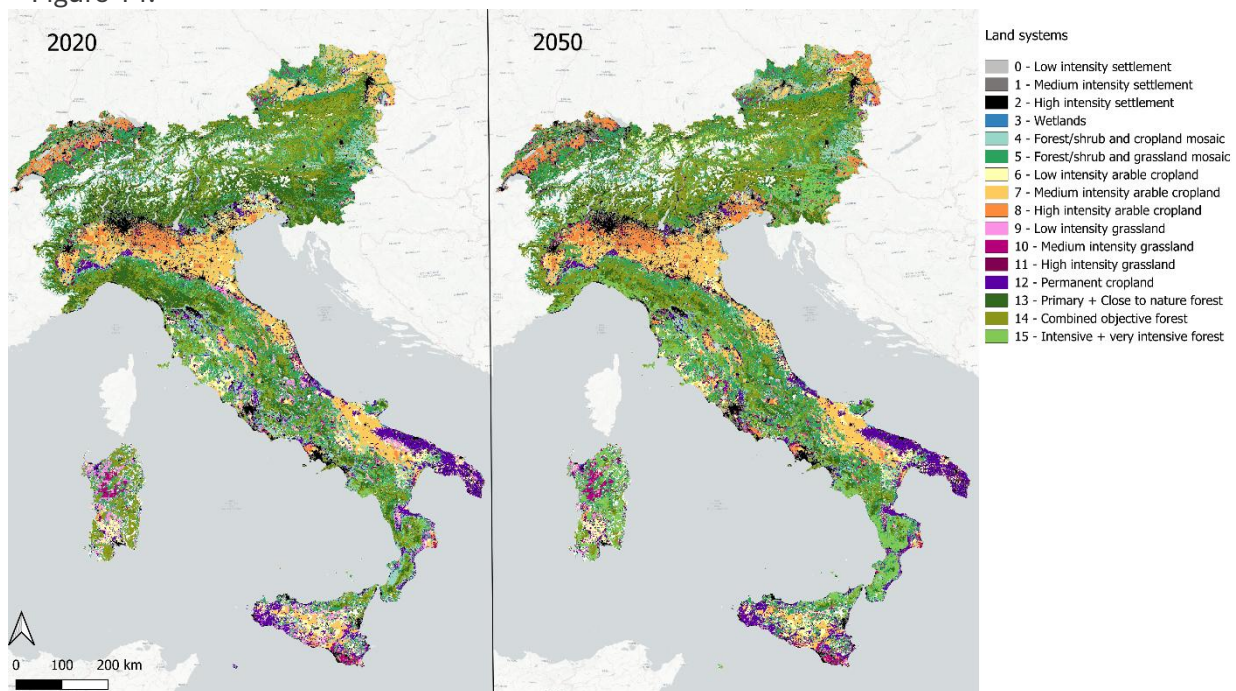


Figure 8. Maps of land systems in starting year 2020 and final year 2050 with the policy scenario Touristification of the cluster with Practice Cases Lucca (IT), Parc Ela (CH) and Green Karst (SI)

- Austria sees intensification of arable cropland, a slight shift from forest, shrub and cropland mosaic to low-intensity arable cropland and a small rise in very-intensive forestry. There is a small decrease in extent of mosaics, but it still covers a large area in Austria. There is also a small increase in medium-intensity settlements.
- Switzerland changes least, with only minor losses in arable cropland. Forests and settlements are virtually static.
- Italy maintains urban extent, intensifies arable cropland and forestry. Total extent of grasslands decreases, but high-intensity grasslands increase
- Slovenia displays the strongest intensification of forestry, while both mosaics decrease by shifting to (very) intensive forestry and high-intensity arable cropland. Also, low-intensity grasslands grow in extent from original forest, shrub and grassland mosaics and primary+close-to-nature forest.



3.3 Possible Landscapes cluster 1: Rewilding

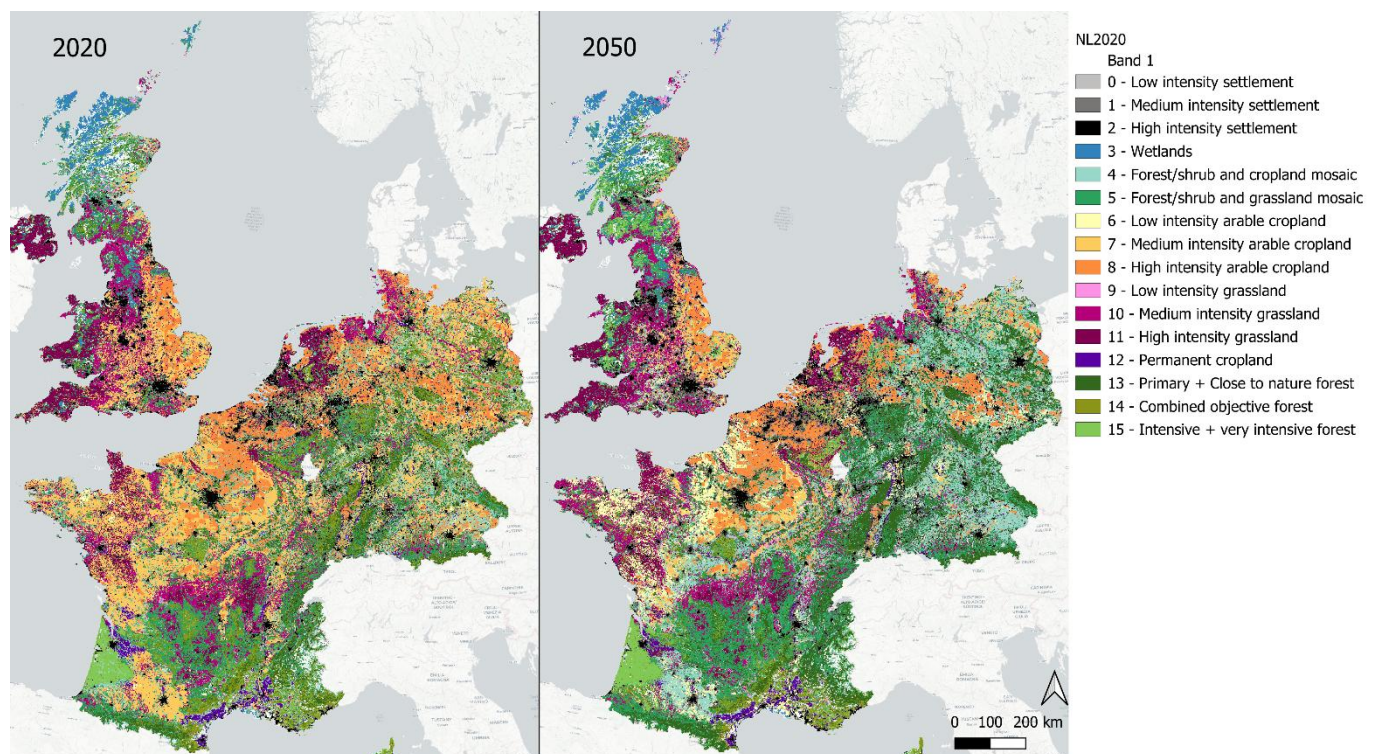


Figure 9. Maps of land systems in starting year 2020 and final year 2050 with the Possible Landscapes scenario Rewilding of the cluster with Practice Cases Zaanstreek-Waterland (NL), 3 Countries Park (BE/NL/DE), Flanders (BE), Île-de-France (FR) and Surrey (UK).

Applying the Rewilding levers pushed the model close to infeasibility for Belgium, France and Germany, because of the ambitious wetland and natural corridor preference layers. After disabling those specific settings, the model still delivers a move toward lower-input agriculture, more diverse forest management and only moderate settlement growth, but with national nuances (see maps in Figure 9). The extensification of arable cropland is mostly visible in western France, while the expansion of the forest, shrub and cropland mosaic is visible in large parts of Germany.

- France sees a clear transition to lower-intensity (see Figure 10). Primary and close-to-nature forests increase, as do both mixed mosaics, whereas permanent crops contract.
- The Netherlands sacrifices much of its mosaics, gains a modest amount of medium-intensity settlement, and registers a small incline in forest area that is carried almost entirely by (very) intensive forestry.
- Belgium has some interesting allocations. Firstly, we observe a strong decline in forest, shrub and cropland mosaics converting to high-intensity arable cropland. Furthermore, medium-intensity grasslands convert to high-intensity, keeping total grassland stable. Medium-intensity arable cropland converts to high-intensity arable cropland and grassland. A substantial part of combined-objective forestry transitions to (very) intensive forestry. Medium-density settlements expand.
- United Kingdom undergoes a shift from primary+close-to-nature forest and combined-objective forestry to (very) intensive forestry. Medium-intensity arable cropland shrinks



and converts for a large share into forest, shrub and cropland mosaic. Other classes remain largely static.

- In Germany, total arable cropland decreases, principally because medium-intensity arable cropland converts to forest, shrub and cropland mosaic. Total forest area stays constant but shifts towards primary/close-to-nature forest at the expense of combined-objective forestry. A part of the medium-intensity grasslands converts to forest, shrub and grassland mosaic.

The aggregated trends for all classes are summarised in Figure 12 and Figure 13.

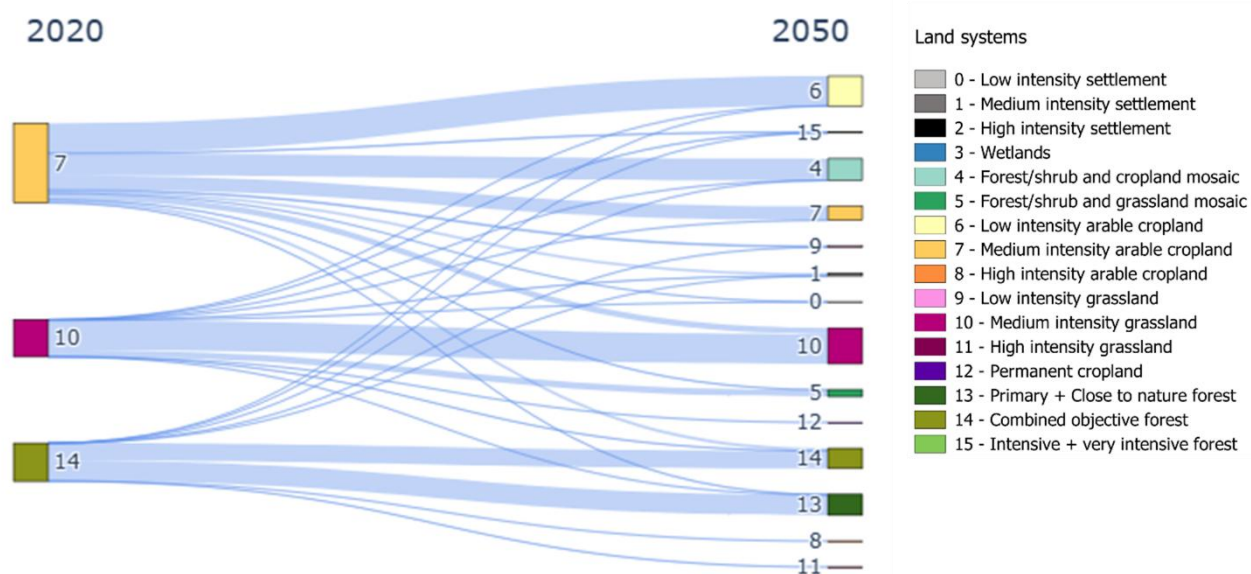


Figure 10. Extensification patterns in France for the Possible Landscapes scenario.



3.4 Possible Landscapes scenario cluster 2: Reactivating

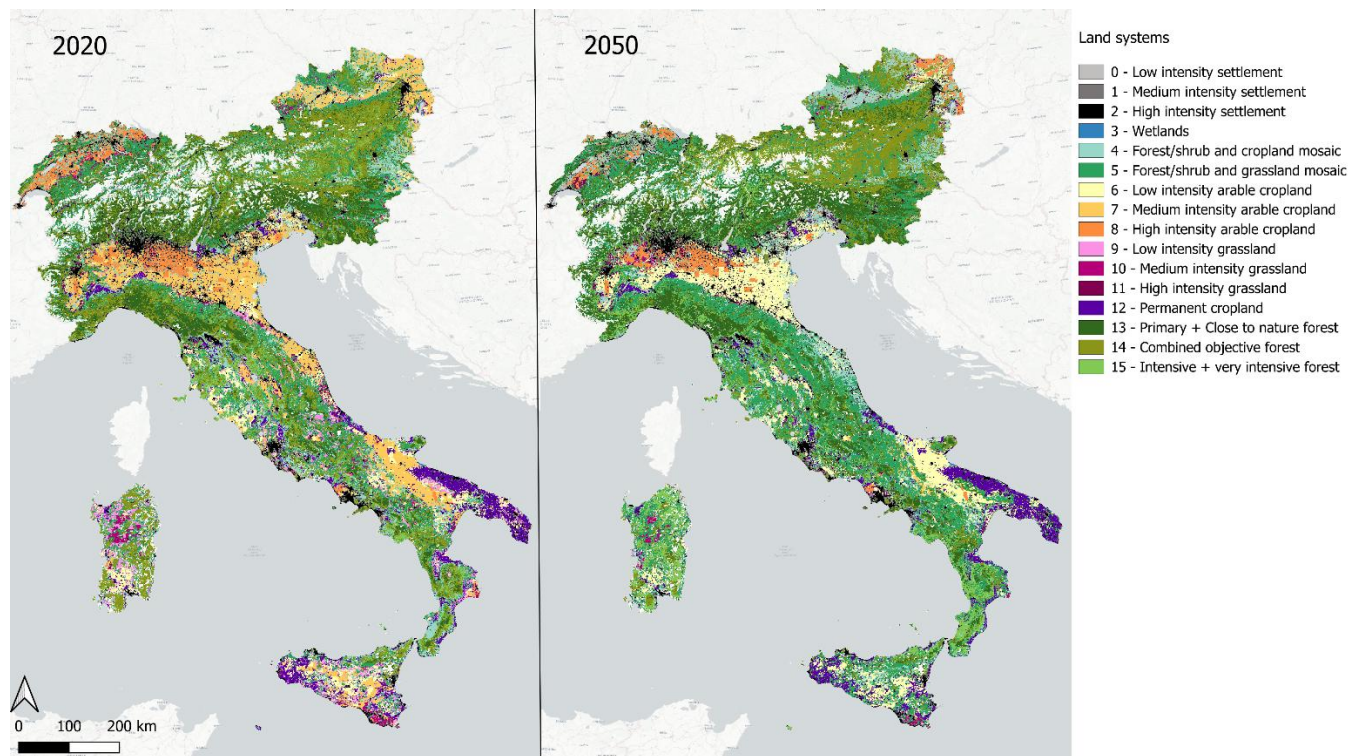


Figure 11. Maps of land systems in starting year 2020 and final year 2050 with the Possible Landscapes scenario Reactivating of the cluster with Practice Cases Lucca (IT), Parc Ela (CH) and Green Karst (SI)

Across all four countries in cluster 2, the Possible Landscapes scenario results in a clear shift toward lower-intensity land systems and a modest expansion of low-intensity settlement area (see maps in Figure 11). The extensification of arable cropland is clearly visible in the Po-Valley in Italy.

- Italy moves towards a more heterogeneous landscape, characterised by an expansion of mosaic classes and a relative increase in low-intensity arable cropland. Overall, arable cropland decreases in extent, grasslands shrink, while permanent crops and urban land remain virtually unchanged.
- Switzerland preserves its existing forest profile, but shows a small loss of both grassland and arable cropland. Low-density settlement grows slightly.
- Slovenia undergoes the most dramatic change: arable cropland almost disappears, supplanted by a modest expansion of forest, notably a new tranche of (very) intensive forestry. High-intensity grassland all but vanishes, leaving the original low-intensity share intact. Forest–cropland mosaics contract slightly; low-density settlement edges upward.
- In Austria, low-intensity settlements grow in extent. Medium-intensity arable cropland shrinks, while low-intensity arable cropland increase, while low-intensity arable cropland increases slightly. Grasslands decrease in extent.

The aggregated trends of the classes in Cluster 2 are visualised in Figure 14.



3.5 Comparison of scenarios

Figure 12 (Cluster 1) and Figure 14 (Cluster 2) show the time-series (2020-2050) for all land-system classes. Figure 13 and Figure 15 aggregate these into grouped totals of respectively cluster 1 and 2 to give more insight into the relative shares under both scenarios.

3.5.1 Key observations for Cluster 1

From Figure 12 and Figure 13, the following observations are drawn:

- Mosaics. Especially, the trend of the mosaics is interesting. In the Possible Landscapes scenario, both mosaic classes grow, which is exactly what the storyline and rules enforce: intensification is blocked and the ecological connectivity steers pixels into mosaics. In the CLD policy scenario, mosaics decline as the scenario prioritises intensification with increasing demands and does not block transitions to higher-intensity systems where we see a decrease in mosaics.
- Permanent cropland. Scenario contrasts are minimal by design: the same CAPRI baseline demand is used in both PL and CLD.
- Agricultural systems. Medium-intensity arable cropland and grassland shrink in both scenarios. Under CLD, they transition to high-intensity, whereas under PL, they step down to low-intensity or transition to mosaics. Total arable cropland extent drops markedly in PL.
- Forests. PL increases close-to-nature/primary forest, while reducing combined-objective, in line with the connectivity and nature-first logic. CLD shows a more minor changes in the forest distribution with some shifts toward more intensive management to meet wood demand.
- Settlements. Patterns are similar across the scenarios: densification over sprawl. Behaviours for settlements do not deviate much between CLD and PL. Both emphasise on densification and limiting urban sprawl.



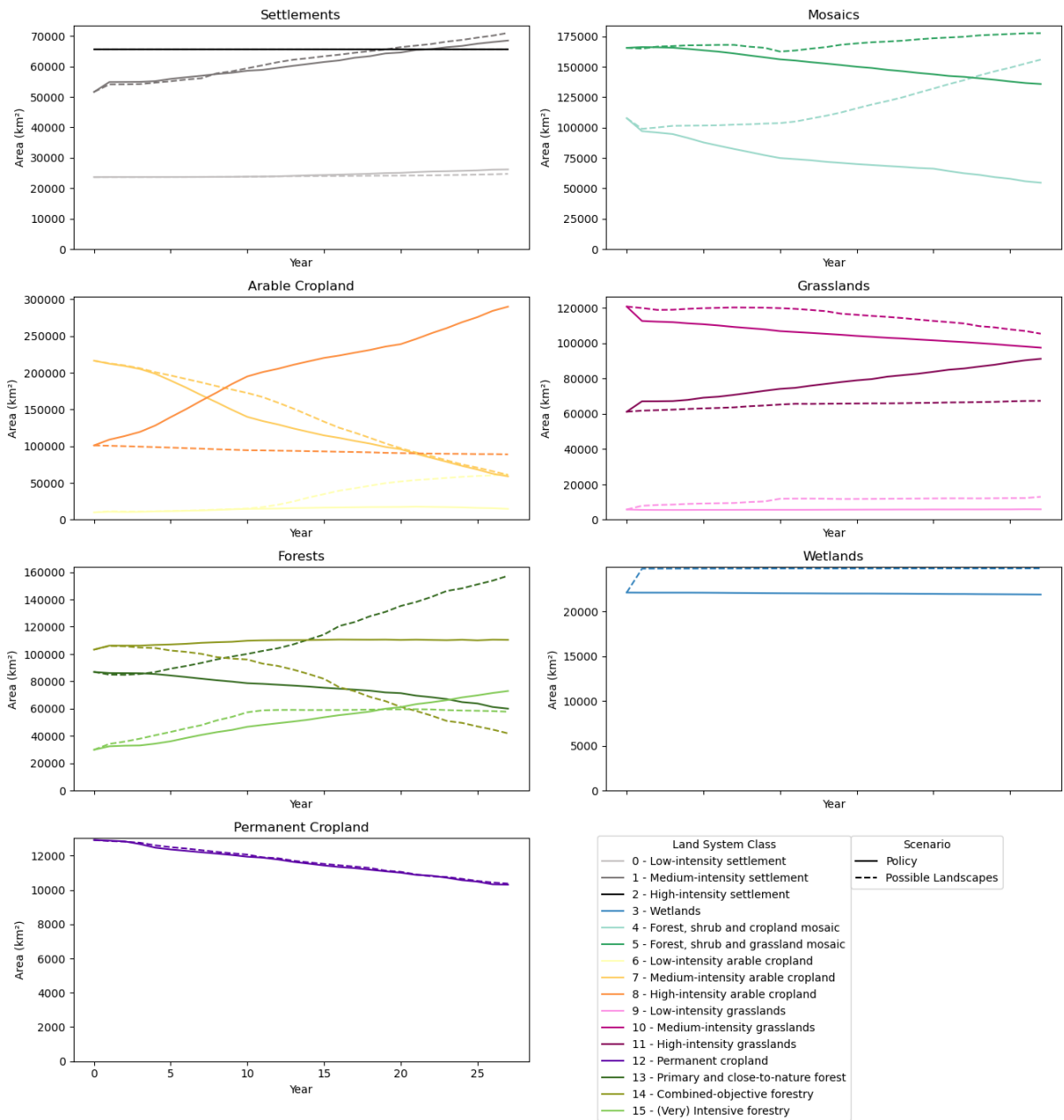


Figure 12. Comparison of all classes in the Policy and Possible Landscapes scenarios for Cluster 1.



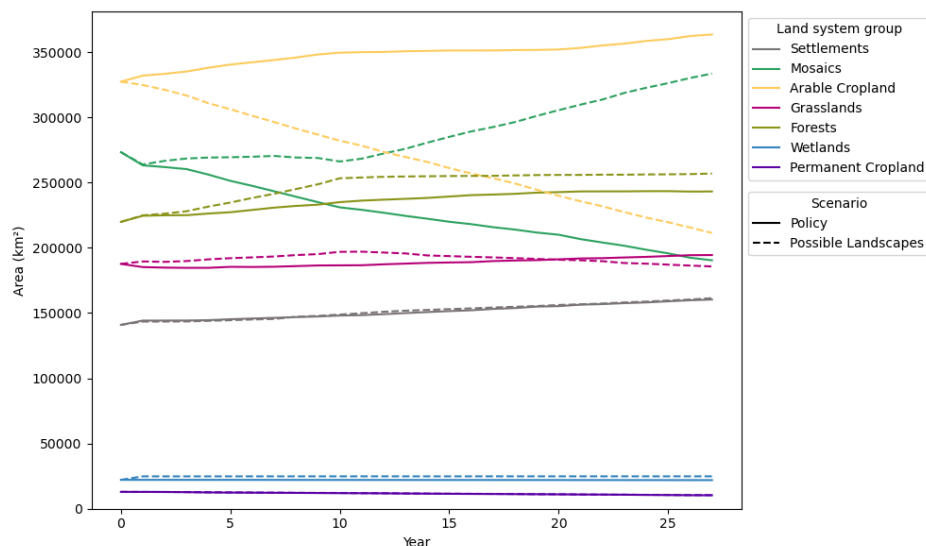


Figure 13. Comparison of grouped system totals of the two scenarios for cluster 1.

3.5.2 Key observations from Cluster 2

Figure 144 and Figure 15 highlight some differences between the CLD and PL scenarios in Cluster 2:

- Settlements. In the PL scenario, low-intensity settlements show an increase. This was not an intended reflection from the scenario. By contrast, the CLD scenario correctly mirrors the densification policy with an increase in medium-intensity settlements rather than sprawl.
- Agriculture. Under PL, total grassland area declines and arable cropland shifts toward low-intensity classes with total arable extent falling. Under CLD, the total extent of arable cropland is roughly stable. For both scenarios, low-intensity grasslands decline. Difference is most distinguished with medium-intensity grasslands: under CLD it rises, under PL it declines. Total extent of grasslands is generally low compared to other systems in cluster 2, but under CLD it remains more or less stable, while under PL it declines.
- Mosaics. In PL, the forest, shrub and grassland mosaic grows steadily, while the forest, shrub and cropland mosaic fluctuates but returns close to its baseline level, so the total mosaic area increases overall. In CLD, by contrast, both mosaic classes remain largely stable.
- Forests. In PL, close-to-nature/primary forest increases and combined-objective forest declines. CLD shows a decrease in close-to-nature/primary forest and a stronger increase in (very-)intensive forestry.



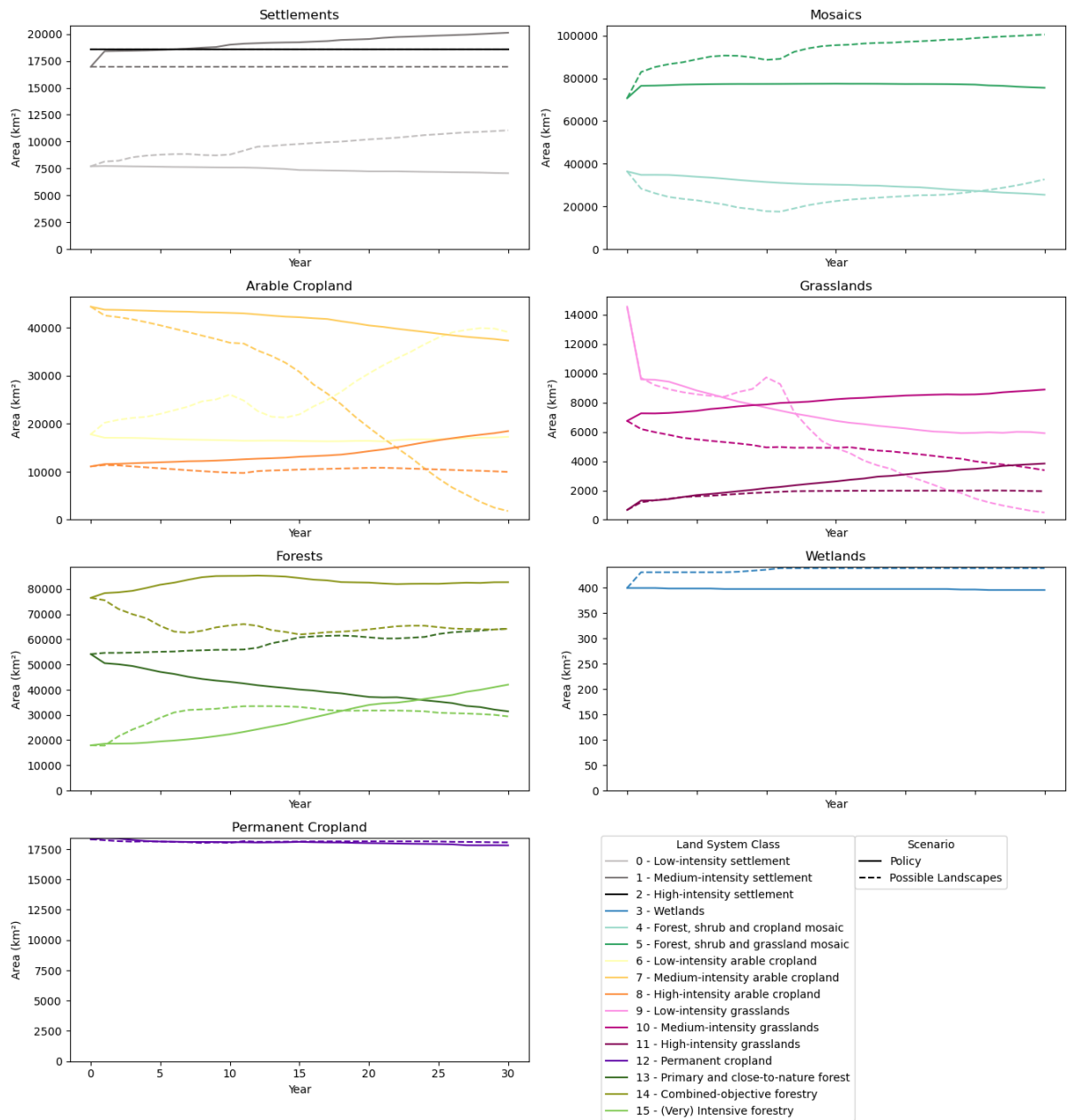


Figure 14. Comparison of all classes in the Policy and Possible Landscapes scenarios for Cluster 2.



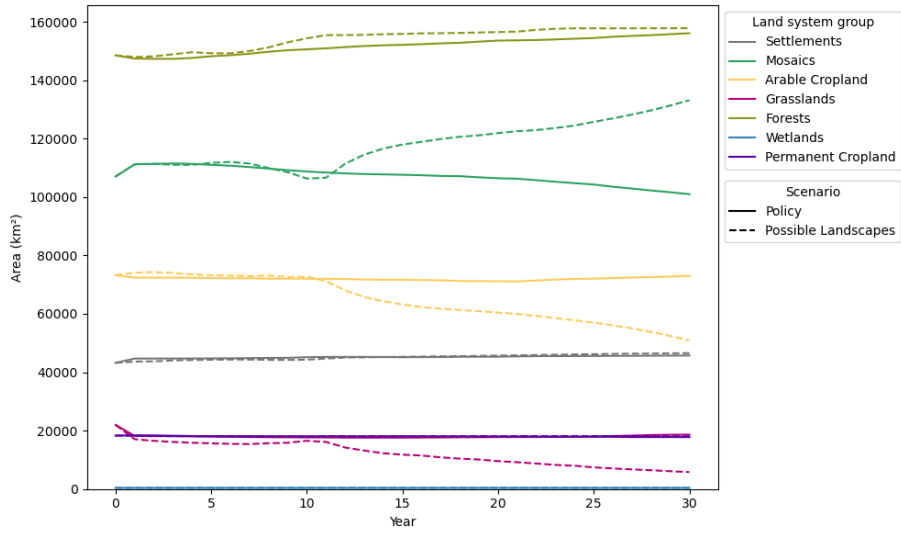


Figure 15. Comparison of grouped system totals of the two scenarios for cluster 2.



4 Discussion and conclusions

4.1 Methodological limitations

While the modelling provides valuable insights, several methodological limitations should be acknowledged. Firstly, the resulting land system maps for 2050 under the Possible Landscapes scenarios do not yet fully align with the stakeholder visions. This gap points to the need for further calibration of the modelling inputs. The challenge is particularly evident in cluster 1, where the visions strongly emphasise extensification, yet quantitative demand trajectories still require a substantial level of agricultural production. Reconciling ambitious PL visions with demand-driven constraints remains a hurdle.

Secondly, the simulations are performed at country level. This approach ensures consistency with national demand baselines and policy, but it also masks important subnational and regional dynamics that are highly relevant to practice cases. In reality, land-use pressures, cultural landscapes, and policy instruments often operate at finer scales than national borders. Future work could explore ways of downscaling or embedding regional detail.

Thirdly, while the Possible Landscapes scenarios were co-designed with stakeholders, their translation into modelling inputs remains a work in progress. Refinement is needed, especially by incorporating insights from the practice case survey (Appendix 2). These survey results can guide a closer match between narratives and quantitative parameters, reducing the gap between stakeholder perspectives and model outputs.

Fourthly, additional demands could be introduced to more directly capture elements of the visions. Examples include explicit quantitative targets for recreation, wetland area, or forest extent. Such demands would strengthen the representation of non-market ecosystem services and restoration objectives. However, increasing the number of demands also raises the complexity of the model and makes it exponentially harder to achieve a feasible solution.

Fifthly, the current CLUMondo typology of 16 land system classes, with nested low-, medium- and high-intensity agricultural subclasses, introduces blind spots. These classes were designed to differentiate cropland, grazing, forestry, and settlements, but they implicitly assume that production scales monotonically with external inputs and mechanisation. As a result, management pathways that decouple yields from synthetic inputs, such as regenerative, organic, or agroecological systems, are spread across multiple classes. This creates three biases: (1) underestimation of the potential output of biologically intensified systems, (2) overestimation of input demand, and (3) a structural tendency to steer simulations toward conventional intensification pathways, constraining the exploration of alternative futures (Kraemer et al., 2025).

Together, these methodological challenges underline that the results should be seen as plausible, stylised futures rather than precise predictions. They provide a structured basis for comparison and dialogue, but they require continuous refinement, particularly in aligning model assumptions with the diverse visions articulated by stakeholders.



4.2 Implications and conclusions

This deliverable provides a spatial expression of the bottom-up visions and policy scenarios from Tasks 3.1, 3.2 and 3.3. The maps demonstrate clear contrasts between policy-driven trajectories, which generally intensify land use and reduce landscape heterogeneity, and the Possible Landscapes vision, which steer toward lower-intensity, multifunctional land systems. At the same time, the modelling highlights important limitations, such as the challenge of aligning ambitions visions with quantitative demand projections, and the difficulty of representing alternative farming systems beyond current intensity-based typology.

Taken together, the results provide a comparative baseline for discussion and stakeholder engagement. They turn narratives into tangible, spatial outcomes helping the forthcoming impact assessments. The maps acts as a pivot between the storylines and impact assessment. This deliverable will feed into the rest of the project as follows:

- Direct input to Task 3.5: The land-system maps are the basis on which biodiversity, ecosystem services and well-being indicators will be overlaid.
- Evidence base for WP4 (Transformation Pathways for Land Use Strategies): WP4 seeks to identify leverage points and draft transformation pathways through the perspective of stakeholders. Deliverable 3.5 provides a quantitative backbone for this, specifically in Task 4.3. In this task, model-validated pathways are calibrated against land-system outcomes and embedded in the CLUMondo runs. This will involve testing how shifts towards more local food systems translate into different land system maps across countries, thereby showing the scale of change required to realise such pathways.



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Appendix 1. Conversion matrices

Table 3, Table 4 and Table 5 contain the conversion matrices used for the PL and CLD scenarios. A 22 denotes that the conversion can only take place outside of Natura2000 and Emerald areas. If a conversion is only allowed after a certain amount of time (e.g. a forest has to stay for at least 30 years before it can transition to another land system), this is indicated with 100+number of time steps. The rows indicate the present land system and the columns the future land system.

Table 3. Conversion matrix of the policy scenario. x=130 in NL, UK, BE, DE, FR, LUX, CH, AT. x=120 in SI, x=110 in IT.

Land system	Code	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Low-density rural settlement	0	1	22	0	0	0	0	0	0	0	0	0	0	22	0	0	0
Medium-density peri-urban settlement	1	0	1	22	0	0	0	0	0	0	0	0	0	0	0	0	0
High-density urban settlement	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetlands	3	22	22	0	1	22	22	22	22	22	22	22	22	22	22	22	22
Forest, shrub and cropland mosaics	4	22	22	0	0	1	1	22	22	22	22	22	22	22	0	1	22
Forest, shrub and grassland mosaic	5	22	22	0	0	1	1	22	22	22	22	22	22	22	0	1	22
Low-intensity arable cropland	6	22	22	0	0	1	1	1	1	1	1	1	1	22	0	1	22
Medium-intensity arable cropland	7	22	22	0	0	1	1	1	1	1	1	1	1	22	0	1	22
High-intensity arable cropland	8	22	22	0	0	1	1	1	1	1	1	1	1	1	0	1	1
Low-intensity grasslands	9	22	22	0	0	1	1	1	22	22	1	22	22	22	0	1	22
Medium-intensity grasslands	10	22	22	0	0	1	1	1	1	1	1	1	22	22	0	1	22
High-intensity grasslands	11	22	22	0	0	1	1	1	1	1	1	1	1	1	0	1	1
Permanent crops	12	22	22	0	0	105	105	105	105	105	105	105	105	1	0	105	105
Close-to-nature forestry + Primary forest	13	22	22	0	0	22	22	22	22	22	22	22	22	22	1	22	22
Combined objective forestry	14	22	22	0	0	22	22	22	22	22	22	22	22	22	1	1	22
Intensive forestry + very intensive forestry	15	22	22	0	0	x	x	x	x	x	x	x	x	x	x	x	1



Table 4. Conversion matrix of the Possible Landscapes scenario of cluster 1. X=130 in NL, UK, BE, DE, FR, LUX, CH, AT. X=120 in SI, X=110 in IT.

Land system	Code	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Low-density rural settlement	0	1	22	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Medium-density peri-urban settlement	1	0	1	22	0	0	0	0	0	0	0	0	0	0	0	0	0
High-density urban settlement	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetlands	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Forest, shrub and cropland mosaics	4	22	22	0	1	1	1	1	0	0	1	0	0	1	0	1	22
Forest, shrub and grassland mosaic	5	22	22	0	1	1	1	1	0	0	1	0	0	1	0	1	22
Low-intensity arable cropland	6	22	22	0	1	1	1	1	0	0	1	0	0	1	0	1	22
Medium-intensity arable cropland	7	22	22	0	1	1	1	1	1	0	1	1	0	1	0	1	22
High-intensity arable cropland	8	22	22	0	1	1	1	1	1	1	1	1	1	1	0	1	1
Low-intensity grasslands	9	22	22	0	1	1	1	1	0	0	1	0	0	1	0	1	22
Medium-intensity grasslands	10	22	22	0	1	1	1	1	1	0	0	1	0	1	0	1	22
High-intensity grasslands	11	22	22	0	1	1	1	1	1	1	1	1	1	1	0	1	1
Permanent crops	12	22	22	0	0	105	105	105	105	105	105	105	105	1	0	105	105
Close-to-nature forestry + Primary forest	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	22
Combined objective forestry	14	0	0	0	0	22	22	22	22	22	22	22	22	22	1	1	22
Intensive forestry + very intensive forestry	15	0	0	0	0	130	130	130	130	130	130	130	130	130	130	130	1



Table 5. Conversion matrix of the Possible Landscapes scenario of cluster 2. X=130 in NL, UK, BE, DE, FR, LUX, CH, AT. X=120 in SI, X=110 in IT.

Land system	Code	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Low-density rural settlement	0	1	22	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Medium-density peri-urban settlement	1	0	1	22	0	0	0	0	0	0	0	0	0	0	0	0	0
High-density urban settlement	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetlands	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Forest, shrub and cropland mosaics	4	22	0	0	1	1	1	1	0	0	1	0	0	1	0	1	22
Forest, shrub and grassland mosaic	5	22	0	0	1	1	1	1	0	0	1	0	0	1	0	1	22
Low-intensity arable cropland	6	22	0	0	1	1	1	1	0	0	1	0	0	1	0	1	22
Medium-intensity arable cropland	7	22	0	0	1	1	1	1	1	0	1	1	0	1	0	1	22
High-intensity arable cropland	8	22	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1
Low-intensity grasslands	9	22	0	0	1	1	1	1	0	0	1	0	0	1	0	1	22
Medium-intensity grasslands	10	22	0	0	1	1	1	1	1	0	1	1	0	1	0	1	22
High-intensity grasslands	11	22	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1
Permanent crops	12	22	0	0	0	105	105	105	105	105	105	105	105	1	0	105	105
Close-to-nature forestry + Primary forest	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Combined objective forestry	14	22	0	0	0	22	22	22	22	22	22	22	22	22	1	1	22
Intensive forestry + very intensive forestry	15	22	0	0	0	130	130	130	130	130	130	130	130	130	130	130	1



Appendix 2. Survey

Background

To validate the assumptions made to go from qualitative storylines to the quantitative requirements of CLUMondo, the authors ran a survey across all 12 practice cases. The survey is used to reflect on the Possible Landscapes and causal loop diagrams and to validate the narrative outcomes.

These insights enable us to finetune the CLUMondo modelling, so that it accurately reflects the visions and policies.



Survey results

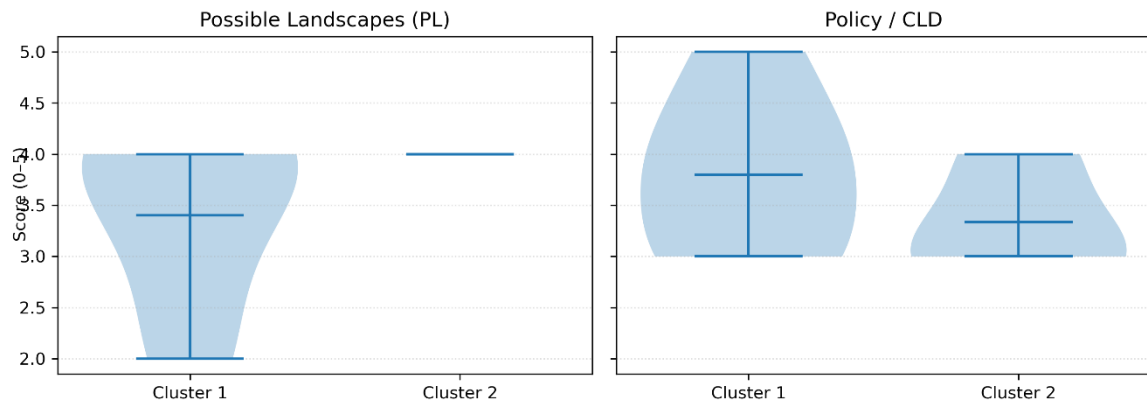


Figure 16. Overall alignment of the modelling assumptions with the Possible Landscapes and CLDs from the Practice Case workshops in the two main clusters.

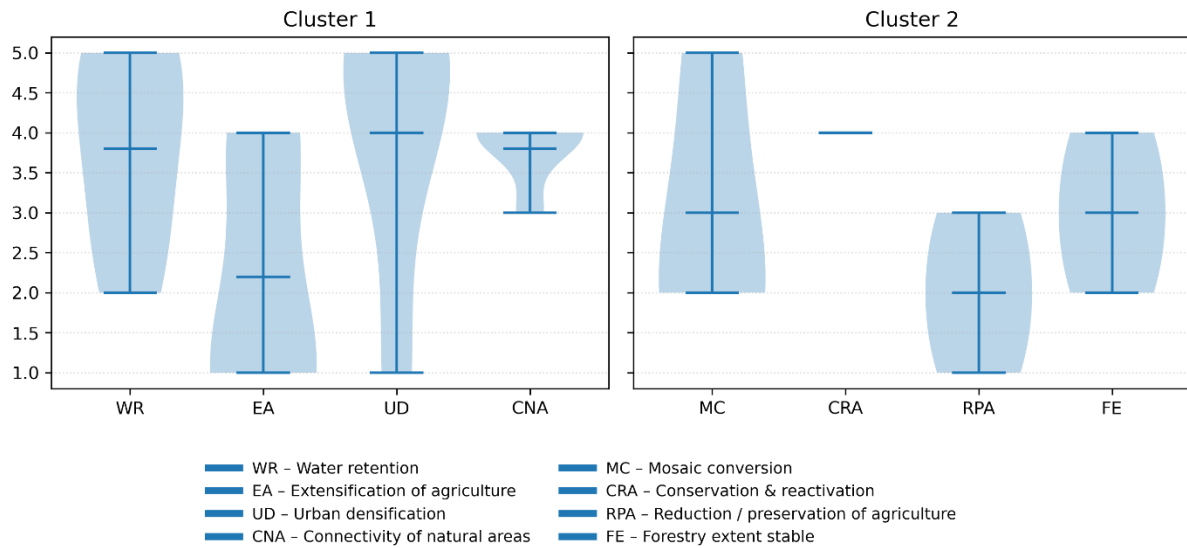


Figure 17. Appropriateness of each individual modelling assumptions of the two main clusters.



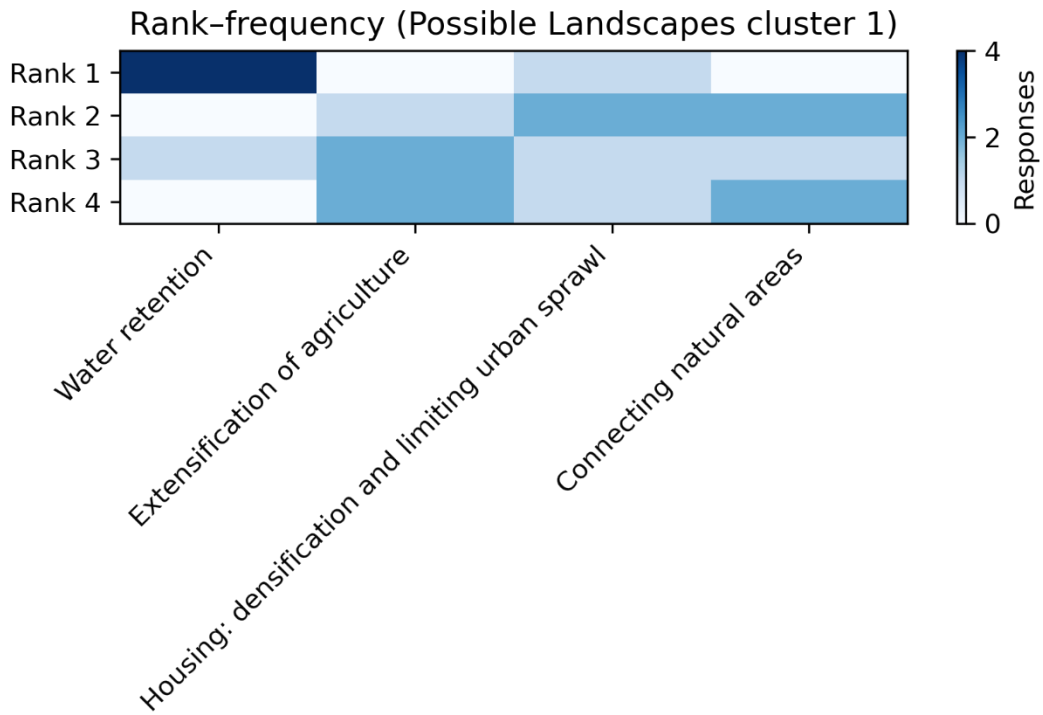


Figure 18. Ranked importance of the modelling assumption in the Possible Landscape scenario of cluster 1.

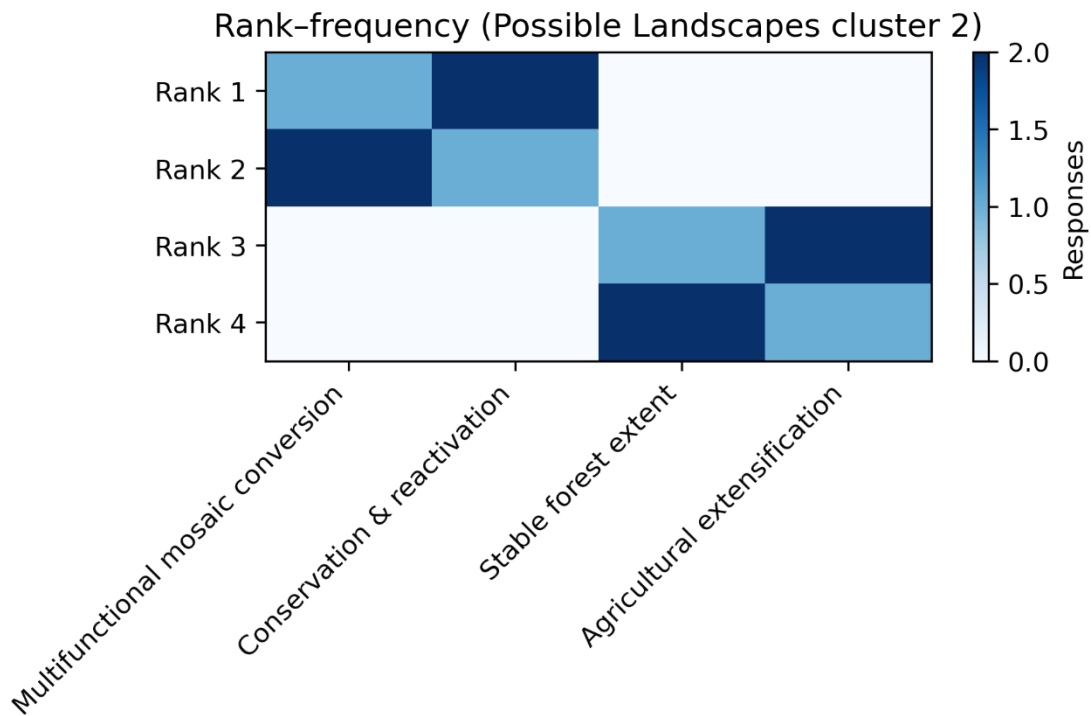


Figure 19. Ranked importance of the modelling assumption in the Possible Landscape scenario of cluster 2.

