Development of guidelines for climate resilient land management - "refine LULUCF inventory"

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Lead authors	Salim Edris, Rodrigo Olave, Susanne Schnabel, Francisco Lavado, Anthony Gabourel
Author(s)	**AFBI:** Salim Edris, Rodrigo Olave **UEX:** Susanne Schnabel, Francisco Lavado, Anthony Gabourel
Contact	**salim.edris@afbini.gov.uk, rodrigo.olave@afnini.gov.uk, schnabel@unex.es, frlavado@unex.es, gabourel@unex.es**
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Executive Summary

This report presents the results from research work carried out in task 3.4 of the AGROMIX project under work package WP3. In general, it assesses the extent to which changes in land use due to management activities arising from different agroforestry systems are reflected in the **Land Use, Land Use Change and Forestry (LULUCF)** carbon inventory, by examining how these practices can help reduce greenhouse gas (GHG) emissions and improve farm resilience. This report only covers agroforestry practices and does not cover mixed farm systems due to the relatively small areas identified in previous work, D1.4 (Schnabel et al., 2022), compared to agroforestry areas, as well as the limited availability of data related to emission and removal factors.

The work of the task is divided into **two main sections**. In the **first section** the **identification and spatial distribution of agroforestry areas at the European scale**, (EU27, UK and Switzerland) is presented, using a spatial approach which consisted of four steps: (1) selection of agricultural areas, including temporary crops, permanent crops, grasslands and heterogeneous classes, (2) estimation of tree cover density in agricultural areas, (3) extraction of small woody features from the total agricultural areas (4) definition of agroforestry areas, including common agroforestry and small woody features agroforestry areas.

The **second section** examines the **impacts of agroforestry systems on the LULUCF carbon inventory**. It uses 1) the agroforestry areas identified in the first section as the main activity data for GHG inventory, 2) identifies the carbon removal rate of agroforestry systems, 3) determines the soil organic carbon stock of silvopastoral and silvoarable areas, and 4) assesses management activities within agroforestry systems which have the potential to affect soil, carbon stocks and increase/reduce emissions based on expert judgement. Then the carbon inventory of these systems was conducted and compared between countries and broad IPCC climatic zones and bio-geographical regions.

A total of 61 million hectares (Mha) of agroforestry land were identified across the EU-27, UK, and Switzerland. Of this, around 15 Mha are classified as common agroforestry areas, while the remaining land is categorised as small woody features agroforestry. In common agroforestry areas, 61.3% (approximately 6.2 Mha) were classified as silvopastoral systems, while the remaining 38.7% **(**3.9 Mha**)** were categorised as silvoarable systems, largely concentrated in three key biogeographical regions: Atlantic, Continental, and Mediterranean — which together cover about 67.9% of the European territorial area.

The analysis of biomass carbon removal revealed that these systems are vital for carbon sequestration, with silvopastoral systems showing carbon removal rates between 1.79 to 2.69 t C ha^{-1} $year^{-1}$, supported by tree densities ranging from 156 to 174 trees ha^{-1}, and tree ages spanning 26 to 68 years. On the other hand, silvoarable systems have slightly different carbon removal rates, ranging from 0.78 to 3.83 t C ha^{-1} $year^{-1}$, with a tree density of 92 to 126 trees ha^{-1}, and ages varying from 18 to 92 years.

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Moreover, carbon inventory analysis showed that while these agroforestry systems contribute significantly to carbon removal, they also emit greenhouse gases due to management activities such as pruning, thinning, and grazing. The emission rates are around 5.73 and 4.7 t CO_2 eq ha^{-1} $year^{-1}$ for silvopastoral and silvoarable systems respectively. Overall, these systems collectively (10.2 Mha) contribute by removing and emitting 88.66 and 54.3 million t CO_2 eq, leading to a total net emission of -34.1 million t CO_2 eq as of 2018.

This suggests that, in 2018, the estimated silvopastoral and silvoarable agroforestry areas have the potential to further enhance LULCF sector GHG mitigation by sequestering an additional -34.1 Mt CO_2 eq. It means that it would increase the sector's GHG removal by roughly 14.9%. Consequently, agroforestry could potentially not only offset all emissions from cropland but also contribute to mitigating approximately 14% of emissions from the grassland category.

This research work highlights the crucial role agroforestry plays in the various climate mitigation strategies across the continent. By strategically incorporating these systems into land use planning, it could contribute significantly to carbon sequestration, reduce agricultural emissions, and ultimately advance sustainable land management practices.

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1 Introduction

1.1 Background

The imperative to mitigate climate change necessitates a comprehensive approach that addresses greenhouse gas (GHG) emissions from all sectors. The Land Use, Land-Use Change, and Forestry (LULUCF) sector play a critical role in this context, acting as both a source and a sink of GHG emissions. While deforestation and land-use changes (e.g., forest land to agricultural land) contribute to emissions, afforestation, reforestation, and sustainable land management practices can sequester significant amounts of carbon. Globally, this sector, LULUCF, including agriculture (AFOLU), on average, accounted for 13-21 % of total anthropogenic GHG emissions in the period 2010-2019 with an emission rate of +5.9 $\pm$ 4.1 Gt CO_2eq/ year. On the EU level, the total emissions from all sectors including both AFOLU and non-AFOLU activities, decreased by 36.11% from 5.4 Gt CO_2 eq in 1990 to 3.4 Gt CO_2 eq in 2020. AFLOU activities were associated with an annual average net source of about 153.28 Mt CO_2 eq, derived from annual average agriculture emissions of about 445.30 Mt CO_2 eq and an annual sink from LULUCF -292.02 Mt CO_2 eq which was mainly driven by Forestland category (UNFCCC, 2022).

Agroforestry systems (AFS), as an integral component of the LULUCF sector, as part of cropland category, offer a promising avenue for enhancing carbon sequestration while maintaining sustainable agricultural productivity, greening landscapes and promoting biodiversity (Mosquera-Losada et al., 2018a). The European Commission defined AFS as land use systems where trees are grown in combination with agriculture on the same land. Silvopastoral, where trees are integrated with grazing animals while silvoarable, is the integration of trees with arable crops (EU, 2013). By integrating trees into agricultural systems, agroforestry can increase carbon storage in both above- and below-ground biomass, as well as in the soil. It can contribute to reducing GHG emissions by mitigating soil erosion, improving soil organic carbon content, and providing renewable energy sources (Rigueiro-Rodríguez et al., 2011).

Numerous studies have estimated AFS areas and quantified their carbon sequestration potentials on European level. The Corine land cover database reports AFS areas roughly 3.3 millon ha, other studies suggested a much larger area of at least 10.6 million hectares (Michael et al., 2015). Michael et al. (2017) used LUCAS land use land cover data to estimate agroforestry areas in the EU 27 region by identifying certain combinations of primary and secondary land cover and/or land management. They estimated AFS areas to be around 15.4 million ha, which is equivalent to about 3.6% of the territorial area and 8.8% of the utilised agricultural area (UAA). A most recent study used LUCAS data from 2018 estimated the total area of agroforestry in the EU28 to be approximately 11.4 million ha, equivalent to 6.4% of UAA (Rubio-Delgado et al., 2023).

More studies have been carried out on estimating AFS biomass carbon and soil organic carbon sequestration. The sequestration rate of biomass depending on factors such as tree species, age, soil, climate, topography. Aertsens et al. (2013) stated that agricultural lands including AFS in the EU member states have the potential to remove up to 1.5 Gt of CO_2 eq annually.

Despite the growing recognition of AFS as a land use management approach in mitigating GHG emissions, comprehensive assessment of their carbon sequestration potentials at a regional scale within the European territorial area are still relatively limited. This study aims to address this knowledge gap by quantifying the agroforestry carbon sequestration potential across the European's primary biogeographical regions: Continental, Mediterranean, and Atlantic. By combining 1) a map of agroforestry area based on a spatially distributed modelling approach, 2) biomass carbon data from the European Agroforestry Federation (EURAF), and 3) standard soil organic carbon default values from IPCC guidelines, aimed at providing valuable insights into the contribution of agroforestry to refine LULUCF sector inventories.

1.2 Definitions of agroforestry

Throughout the world, at one period or another, the term agroforestry has been defined as the practice of integrating more than one land use/cover practice into a single land unit. The examples are numerous. In tropical central America, it was known as the practice of cultivating a wide variety of crops in relatively small plots, with tall trees such as papaya or coconut in combination with crops like maize, bananas and squash growing in layers beneath. A different example of agroforestry systems in Asia was the shifting cultivation practised by Hanunoo people in Philippines, a practice of deliberately leaving certain trees when clearing the forests for rice farming. The remaining trees were expected to provide partial shade, protecting crops from excessive sunlight and helping conserve moisture. In Africa, the cultivation of crops such as maize, yams and beans were grown under scattered trees practiced mainly by Yoruba people in western Nigeria being another example, of a multi-layered farming system, with trees, shrubs, and crops growing together. Across these regions, these diverse layered systems were meant to mimic natural forests, optimising land use and maintaining biodiversity, and were primarily focused on food production, with trees serving to support and enhancing agricultural practices (ICRAF et al., 1987; KING & CHANDLER, 1978).

To great extent, the contemporary definitions and examples of agroforestry practices and systems are consistent with those historical ones, although they represent an evolution of those traditional practices. The term agroforestry was officially introduced in 1977 as part of the early international efforts to initiate research on integrated production systems involving trees and crops(Nair et al., 2021).

Numerous discussions and arguments were held to define the term with the focus on two important characteristics common to all forms of agroforestry systems to separate them from other forms of land use, which are 1) the deliberate growing of woody perennials on the same unit of land in combination with agricultural crops and/or animals, either in some form of spatial mixture or sequence. 2) there must be a significant interaction (positive and/or negative) between the woody and non-woody components of the system, either ecological and/or economical. The ideas from the discussions were later refined at ICRAF and a definition was suggested “agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land in combination with agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence (Nair et al., 2021). In agroforestry systems, there are both ecological and economical interactions between the different components. Ever since several definitions were introduced, some are presented in table 1.

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Table 1. Definitions of agroforestry relevant to task aims

	Definition	Reference
Agroforestry 1	*Agroforestry systems mean land use systems in which trees are grown in combination with agriculture on the same land.*	Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005
Agroforestry 2	*Agroforestry means land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same parcel or land management unit without the intention to establish a remaining forest stand. The trees may be arranged as single stems, in rows or in groups, while grazing may also take place inside parcels (silvoarable agroforestry, silvopastoralism, grazed or intercropped orchards) or on the limits between parcels (hedges, tree lines).*	Establishment of agroforestry systems. Measure 8. Article 21(1) (b) and 23 of Regulation (EU) No 1305/2013 of the European Parliament and of the Council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD)
Silvoarable	*Silvoarable agroforestry consists of widely spaced trees inter-cropped with annual or perennial crops.*	(Eichhorn et al., 2006)
Silvopastoral	*Are those systems that combine tree growing with the production of livestock. These systems typically include pasture systems containing trees that are widely spaced or planted in clusters throughout the pasture.*	(De-Sousa et al., 2023)

The Food and Agriculture Organisation of the United Nations (FAO) defined agroforestry as a collective form of land use systems and technologies in which woody perennials (e.g. trees, shrubs, palms or bamboos) and agricultural crops or animals are used deliberately on the same parcel of land in some form of spatial and temporal arrangement. It further defines it as a dynamic, ecologically based natural resource management system that, via the incorporation of trees in agricultural landscapes or through the production of agricultural products in forests, diversifies and sustains production for increased economic, social and environmental benefits (Simone et al., 2018).

Moreover, the 2nd AgForward research project on agroforestry in the EU defined the term as “ the practices of deliberately integrating woody vegetation (trees or shrubs) with crop and/or livestock production systems to benefit from the resulting ecological and economic interactions (Augere-Granier, 2020).
Despite these definitions emphasising the term “deliberately” to stress that agroforestry systems are man-made rather than naturally occurring, the specific configuration of number of trees or perennial woody

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plants, the density of crops, or the stock of animals per unit of land have not yet been clearly defined for agroforestry systems.

A significant body of research has classified agroforestry systems. (Augère-Granier, 2020) Stated that the main types of agroforestry include silvopastoral and silvoarable systems, forest farming, hedgerows, riparian buffer strips and kitchen gardens. A recent study by Susanne Schnabel et al. (2020) classified agroforestry systems in Europe into six classes using LUCAS dataset based on criteria such as the primary and secondary land cover and grazing. These six classes are grazed permanent crops, intercropped permanent crops, silvopastoral, silvoarable, agro-silvopastoral, and home-gardens. For the purpose of this research work, a carbon inventory, we only considered two agroforestry systems: silvopastoral and silvoarable agroforestry systems, which are defined in Table 1.

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2 Extent and spatial distribution of agroforestry areas in Europe

Anthony Gabourel Landaverde, Susanne Schnabel, J. Francisco Lavado Contador
University of Extremadura

2.1 Overview

The aim of this work is to identify agroforestry areas in the European Union 27 Member States, United Kingdom and Switzerland, using available datasets at the European scale, such as land cover, tree density and small woody features maps. The spatial approach used for this analysis consisted of four steps (Figure 1): (1) selection of agricultural areas, including temporary crops, permanent crops, grasslands and heterogeneous classes, (2) estimation of tree cover density in agricultural areas, (3) extraction of small woody features from the total agricultural areas (4) definition of agroforestry areas, including common agroforestry and small woody features agroforestry areas.

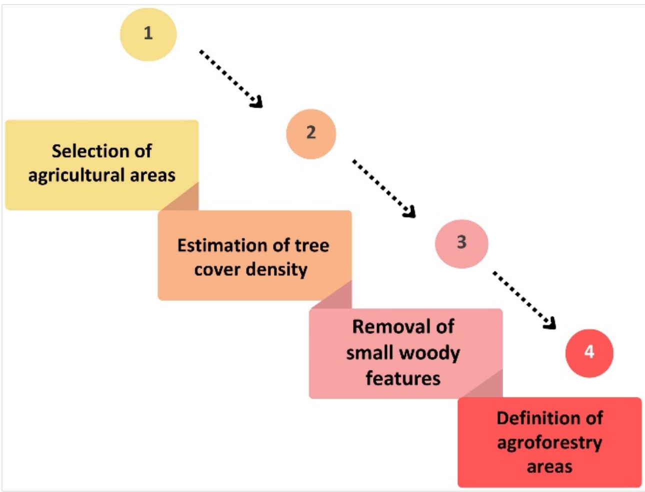

Figure 1. Methodology used for the estimation of agroforestry areas in the EU27, United Kingdom and Switzerland.

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2.2 Methodology

2.2.1 Selection of agricultural areas

The Land-Use based Integrated Sustainability Assessment (LUISA) base map from 2018 (Batista & Pigaiani, 2021b) was used to estimate the total agricultural area in the European Union (EU) 27 Member States, the United Kingdom (UK) and Switzerland (CH) (Table 2). The LUISA base map is a modified and improved version of the CORINE land cover 2018 map, with 17 artificial land use/cover categories (instead of 11 in CORINE), with a geographical coverage for all Europe and a spatial resolution of 100 m. This refined land cover map significantly enhances the resolution of the included classes, facilitating more accurate estimation of the total agricultural area.

Temporary crops (*non-irrigated arable land, permanently irrigated arable land and rice fields*), grasslands (*pasture and natural grasslands*), permanent crops (*vineyards, fruit trees and berry plantations, and olive groves*) and heterogeneous classes (*complex cultivation patterns, land principally occupied by agriculture, annual crops associated with permanent crops and agroforestry*) were selected as agricultural areas for further analysis aimed at the determination of agroforestry areas in Europe. It should be noted that the classes "annual crops associated with permanent crops" and "agroforestry" are already identified within the LUISA land cover map as agroforestry areas.

Table 2. List of datasets used to estimate the agroforestry area in the EU27, United Kingdom and Switzerland.

Map	Description	Temporal coverage	Pixel resolution (m)	Source
LUISA Land cover map	Land cover/Land use map	2018	100	(Batista & Pigaiani, 2021b)
Tree cover density	Percentage of tree crown cover	2018	100	(Copernicus Land Monitoring Service, 2023b)
Small woody features	Herbaceous features like hedgerows, shrubs, and small clusters of trees	2018	100	(Copernicus Land Monitoring Service, 2023b)
Global canopy height	Tree height map	2009-2020	1	(Tolan et al., 2024)
Forest type map	Forest classification for three thematic classes: all non-forest areas, broadleaved forest, coniferous forest.	2018	100	(Copernicus Land Monitoring Service, 2023b)

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Furthermore, the high-resolution layers provided by the (Copernicus Land Monitoring Service, 2023b), such as the Tree Cover Density, the Small Woody Features and the Forest Type maps, as well as the tree height map produced by Tolan et al. (2024), were utilised to estimate and characterise agroforestry areas across Europe. These datasets offer detailed information on vegetation cover and landscape elements, facilitating a more comprehensive assessment of agroforestry areas (Table 2).

2.2.2 Estimation of tree cover density and tree height in agricultural areas

Tree cover density. The 2018 tree cover density map provided by the Copernicus Land Monitoring Service (2023b) is a detailed dataset showing the percentage of tree cover across Europe, with a resolution of 100 meters. It ranges from 0% to 100%, indicating areas with no tree cover to full canopy coverage. Created using satellite imagery and remote sensing, this map is crucial for environmental monitoring, forest management, land use planning and climate change studies. It covers the entire European continent and is publicly accessible through the Copernicus Land Monitoring Service, serving as a tool for sustainable forest resource management, biodiversity preservation and environmental monitoring.

Tree cover density was estimated for the total agricultural area within the study region. The agricultural areas were then divided into two groups: those reporting between 1 - 10% tree cover density and those showing more than 10% tree cover density. This differentiation allows for a clearer distinction between areas with higher tree densities and those with lower densities, while still recognising the significance of tree presence in both categories. Agricultural areas, identified in the previous step, that have more than 1% of tree cover were considered agroforestry.

Tree height. The Global Canopy Height Maps dataset provides detailed information on tree canopy heights worldwide, covering the period from 2009 to 2020 (Tolan et al., 2024). With 80% of the data sourced from imagery taken between 2018 and 2020 and a spatial resolution of 1 meter, this dataset serves as a valuable reference for enhancing field-based measurements of carbon in carbon credit monitoring and verification schemes.

Canopy height was estimated for all agricultural areas, including final agroforestry maps, offering a comprehensive overview of tree canopy presence and height across various landscapes. To ensure consistency in spatial resolution across all maps, the tree height dataset was resampled to a 100-meter pixel size using the bilinear interpolation technique, which determines the new value of a cell based on a weighted distance average of the four nearest input cell centres.

2.2.3 Extraction of small woody features from agricultural areas

Agricultural land, such as cropland or grazed grasslands, may include woody vegetation (shrubs and trees), such as hedgerows, windbreaks, riparian vegetation, and are widespread in many parts of Europe (Mosquera-Losada et al., 2018b). Several authors consider these systems as a type of agroforestry (Mosquera-Losada et al., 2009) because the woody vegetation offers additional ecosystem services, such as increase of biodiversity, shading and organic matter input to soils.

The 2018 small woody features dataset from Copernicus provides a detailed map of hedgerows, tree lines, and small wooded patches across Europe, focusing on capturing vegetation structures that are often under-represented in larger-scale maps. With its high resolution of 100 meters, the dataset illustrates the density of small woody features, ranging from 0% in areas without these features to 100% in areas with high

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concentrations. These critical elements contribute to biodiversity, landscape connectivity, and ecological stability. This dataset, provided by the Copernicus Land Monitoring Service (2023b) is a valuable resource for environmental monitoring, landscape management, and conservation planning.

Agricultural areas reporting more than 1% of small woody features were extracted from different land cover types, including temporary crops (non-irrigated and irrigated arable land, rice fields), permanent crops (olive groves, fruit tree and berry plantations, vineyards), grasslands (pastures, natural grasslands), and heterogeneous agricultural areas. This extraction was conducted to assess their extent and spatial distribution throughout the study area.

2.2.4 Definition of agroforestry areas

Agroforestry areas were categorised into two classes: **common agroforestry** and **small woody features agroforestry**. Common agroforestry areas were identified from specific land cover classes based on the tree cover density analysis, including temporary crops (such as non-irrigated arable land, permanently irrigated arable land, and rice fields), grasslands (pastures and natural grassland), and areas classified as "land principally occupied by agriculture". Permanent crops and the "complex cultivation patterns" class were excluded from the common agroforestry estimation, as these areas already have trees, and there is insufficient information on their land management practices, i.e. whether they are grazed or include annual crops. For example, areas with permanent crops can only be considered agroforestry if they also include either grazing livestock or cultivation of annual crops

In addition to these classes, the classes "agroforestry" and "annual crops associated with permanent crops", which are existing agroforestry areas identified in the LUISA map, were incorporated into the final common agroforestry map. This group is designated as "common" agroforestry to differentiate between traditional agroforestry practices, such as silvopastoral and silvoarable systems or intercropped permanent crops, from the small woody features agroforestry areas.

Once the assessment of tree cover density was conducted, a boundary clean algorithm was applied to reclassify the pixels and create a final map of **common agroforestry**. This algorithm smooths the boundaries between zones using mathematical morphology techniques, specifically expansion (dilation) and shrinking (erosion) (Serra, 1983). Each input pixel was evaluated based on its immediate orthogonal and diagonal neighbours, prioritising areas with higher tree cover densities (over 10%) compared to those with lower densities (1-10%). Following the application of this algorithm, a new classification was generated, resulting in revised groups of cells and the removal of noise and isolated cells deemed less important for the landscape scale (Figure 2).

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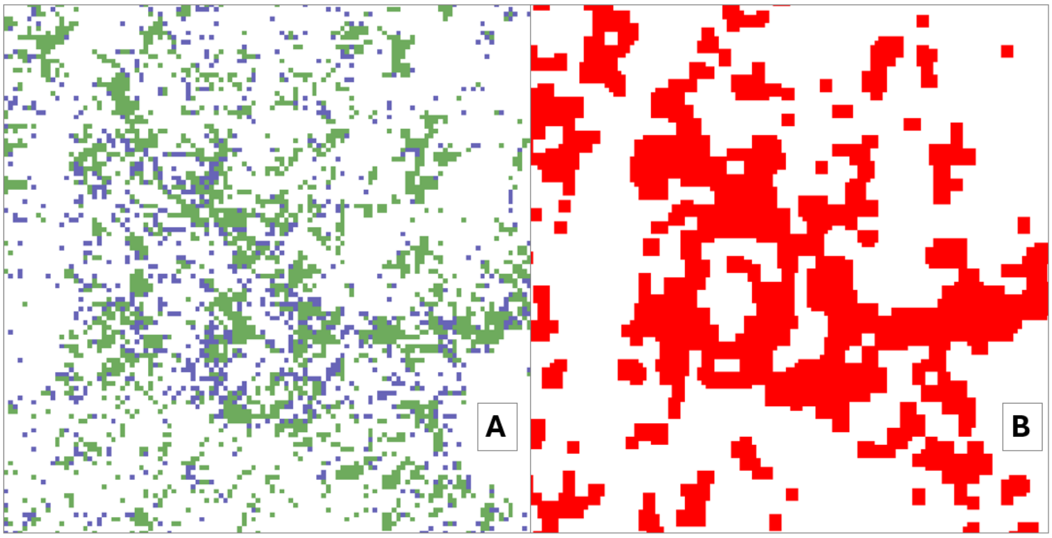

Figure 2. Agricultural areas with tree cover density between 1 - 10% (in violet) and above >10% (in green) before applying the boundary clean algorithm (A) and after applying the algorithm (B).

Regarding **small woody features agroforestry**, these areas were identified within temporary crops, grasslands, permanent crops, and the heterogeneous land cover group. This was done by applying the small woody features mask (Copernicus Land Monitoring Service, 2023b) to extract these areas from the total agricultural areas and avoid overlaps with the common agroforestry areas.

Definition of silvopastoral and silvoarable areas

The final map of common agroforestry was reclassified into two categories: **silvopastoral** and **silvoarable**, based on the original land cover of the pixels (Table 3). Pixels originally classified as "non-irrigated arable land", "permanently irrigated arable land", "rice fields", and "land principally occupied by agriculture" were categorised as "silvoarable" due to their higher tree densities in arable environments. Meanwhile, pixels associated with "pastures", "natural grasslands", and "agroforestry" areas were reclassified as "silvopastoral", as these areas also exhibited higher tree densities and were influenced by grazing practices, either heavily or lightly (Copernicus Land Monitoring Service, 2023a). An overview of the methodology used to create the agroforestry maps is presented in Figure 3.

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Table 3. Reclassification of common agroforestry areas in two classes: silvopastoral and silvoarable.

Original class	New class
Non irrigated arable land	**Silvoarable**
Permanently irrigated arable land	
Rice fields	
Land principally occupied by agriculture	
Pastures	**Silvopastoral**
Natural grasslands	
Agroforestry	

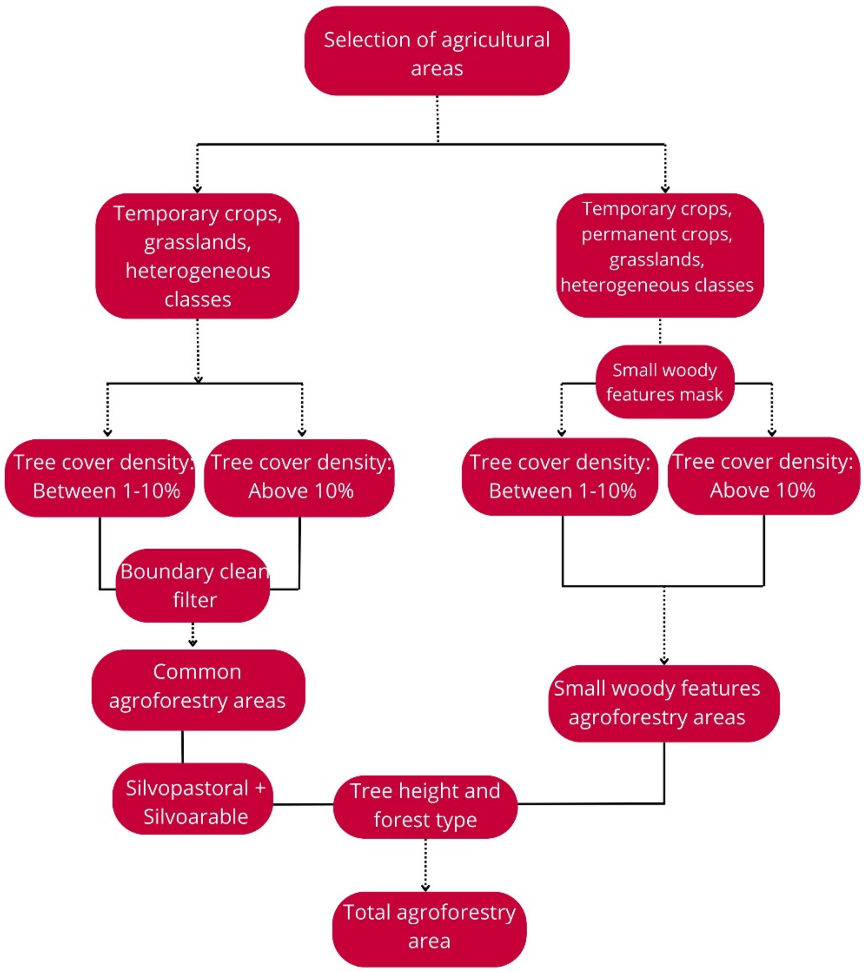

Figure 3. Methodology used for the development of the agroforestry map in Europe.

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2.3 Results

2.3.1 Estimation of the agricultural area

Temporary crops (*non-irrigated arable land, permanently irrigated arable land and rice fields*), grasslands (*pastures and natural grasslands*), permanent crops (*vineyards, fruit trees and berry plantations, and olive groves*) and heterogeneous classes (*complex cultivation patterns and land principally occupied by agriculture*) were selected as the basic land uses for estimating the agroforestry area in Europe. In total, all classes amounted to 1,938,326 km^2 (Table 4).

Table 4. Surface areas occupied by different agricultural land uses considered in the determination of agroforestry areas, based on land cover classes obtained from the LUISA base map.

Land cover class	Area (km^2)	Area (%)
Non irrigated arable land	1,018,692	52.6
Permanently irrigated arable land	39,860	2.1
Rice fields	6,370	0.3
Total temporary crops	***1,064,922***	***54.9***
Pastures	447,854	23.1
Natural grasslands	104,901	5.4
Total grasslands	***552,755***	***28.5***
Vineyards	34,385	1.8
Fruit trees and berry plantations	25,527	1.3
Olive groves	45,277	2.3
Total permanent crops	***105,189***	***5.4***
Complex cultivation patterns	113,036	5.8
Land principally occupied by agriculture	102,424	5.3
Total heterogeneous classes	***215,460***	***11.1***
Total area	**1,938,326**	**100.0**

Moreover, the LUISA map already incorporates two land cover classes related to agroforestry: “agroforestry” and “annual crops associated with permanent crops”. The “agroforestry” class is primarily confined to traditional silvopastoral systems, such as “dehesas” in Spain or “montados” in Portugal, and certain regions in Sardinia, Italy. The “annual crops associated with permanent crops” class, which involves the combination of temporary crops with permanent crops, is another form of agroforestry found in countries like Italy, Portugal, and Cyprus. However, this class is not categorised as agroforestry within the LUISA map. In Table 5 the total agroforestry areas identified in the LUISA land cover map are presented.

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Table 5. Agroforestry areas identified in the LUISA base map.

Land cover class	Area km^2
Annual crops associated with permanent crops	3,901
Agroforestry	30,110
Total area	34,011

2.3.2 Estimation of tree cover density and tree height in agricultural areas

Tree cover density in agricultural areas

Mean tree cover densities for the different land cover types are presented in Figure 4. Tree cover density was highest in certain permanent crops, particularly olive groves, fruit orchards, and berry plantations, where higher concentrations of trees contributed to a denser canopy. In contrast, temporary crops, such as permanently irrigated arable land, rice fields, and non-irrigated arable land, exhibited the lowest tree cover density (Figure 4). These temporary crops, which collectively made up over 50% of the agricultural area, typically lack long-term vegetation cover, resulting in significantly lower canopy density, with only 3.5%.

Heterogeneous classes exhibited relatively high tree cover density, averaging 13.7%, and accounted for 12.6% of the agricultural area. These classes include various mixed land uses such as areas where agriculture is interspersed with natural vegetation or other land cover types. Within this category, agroforestry areas, identified in the LUISA map, had the highest tree cover density at 19.3%, except for permanent crops. Agroforestry, which integrates trees with crops or livestock, supports higher canopy density due to the intentional preservation of tree cover. Land principally occupied by agriculture, with natural vegetation also present, showed a tree cover density of 16.7%. This land cover type, typically characterised by a mosaic of crops and natural habitats, contributes to the relatively high tree cover.

In contrast, grasslands, which together represented 28% of the total agricultural land, exhibited a mean tree cover density of 6.9%. These areas, including both natural and managed grasslands, typically feature lower tree cover as they are dominated by herbaceous vegetation with scattered trees or shrubs. The lower tree cover density in grasslands reflects their primary use for grazing, where maintaining open areas is often prioritised.

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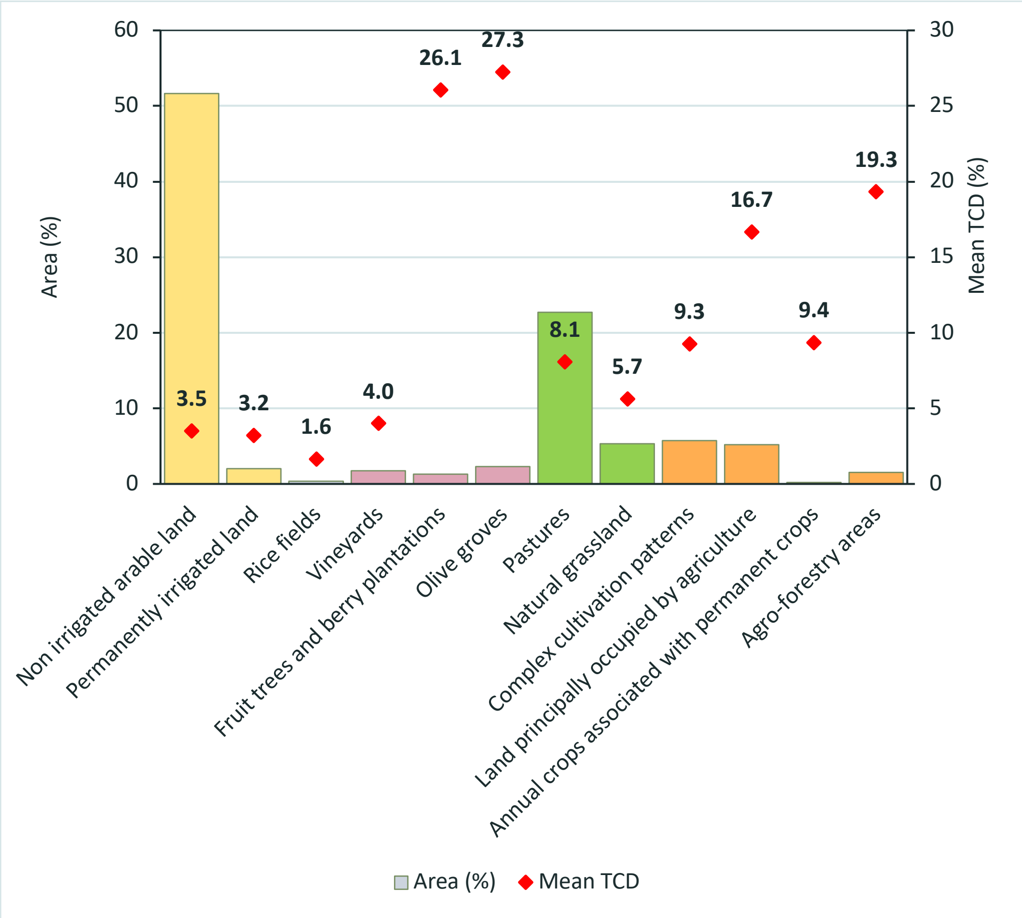

Figure 4. Area (%) in proportion to the total agricultural area and mean tree cover density (TCD) (%) by land cover type.

Across all land cover groups, a significant portion of the land was reported as non-tree-covered areas. However, there were also notably high percentages of tree-covered areas, particularly within the 10% to 100% tree cover density range. Areas with 1% to 10% tree cover density were also substantial, but less prevalent. Permanent crops, such as olive groves and orchards, stood out as the group with the highest percentage of tree-covered surface, with almost 50% of their area exhibiting tree cover. Heterogeneous classes, which include mixed land uses like agroforestry and agricultural mosaics, followed, with 25% of their area displaying tree cover densities between 10 and 100% (Table 6).

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Table 6. Area (%) in proportion to the total area in grasslands, temporary crops, permanent crops and heterogeneous classes, falling into different tree cover density classes ranging from 0% to 100%.

Tree cover density (%)	Grasslands (%)	Temporary crops (%)	Permanent crops (%)	Heterogeneous classes (%)
0 (non-tree covered areas)	88.7	94.9	51.8	73.2
1-10	0.2	0.2	9.2	1.9
10-100	11.0	4.9	39.1	25.0
Unclassifiable (no satellite image, clouds, shadows, or snow)	0.1	0.0	0.0	0.0

Tree height in agricultural areas obtained from the LUISA land cover map

Tree height values varied across different land use types. In permanent crops and heterogeneous land classes, 87% and 67% of the canopy cover, respectively, consisted of trees with heights ranging from 1 to 5 meters. In contrast, temporary crops and grassland areas exhibited lower tree coverage within this height range, with 57.5% and 58%, respectively (Table 7). These differences can be attributed not only to the nature of land use in each category but also to their spatial extent, as temporary crops and grasslands together accounted for 83.4% of the agricultural area. Notably, 10.7% of the canopy cover in heterogeneous land classes featured trees taller than 10 meters, indicating areas where natural vegetation is permitted to thrive alongside agricultural activities.

Table 7. Area (%) in proportion to the total area in grasslands, temporary crops, permanent crops and heterogeneous classes, falling into different tree height classes ranging from 1 to 25 m.

Canopy height (m)	Grasslands (%)	Temporary crops (%)	Permanent crops (%)	Heterogeneous classes (%)
1-5	58.0	57.5	87.0	67.0
5-10	26.8	26.2	9.7	22.3
10-15	10.9	11.4	2.6	8.0
15-20	3.6	4.0	0.7	2.3
20-25	0.7	0.8	0.1	0.4

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2.3.3 Extent and spatial distribution of agroforestry areas

2.3.3.1 Common agroforestry areas

Common agroforestry areas by country. Common agroforestry areas amounted to 150,443 km^2 in the EU27 Member States, United Kingdom and Switzerland, with notably high values in Spain, Italy and Portugal (Figure 5), being also a significant portion of their agricultural area, ranging from 10% to 27%. Germany and France also reported significant values of agroforestry land, although these areas represented less than 10% of their agricultural area. Fewer agroforestry areas were reported in smaller countries, such as Slovenia, Malta and Netherlands, where common agroforestry areas represented less than 5% of their total agricultural area (Table 8).

The variation in agroforestry coverage among countries can be attributed to differences in land-use policies, climatic conditions, and historical agricultural practices. In Mediterranean countries like Spain, Italy, and Portugal, agroforestry systems have been traditionally integrated into farming landscapes, such as silvopastoral systems, where trees are combined with livestock grazing (Augère-Granier, 2020; Fotakis et al., 2024). In contrast, countries like Slovenia and Malta, where agriculture is practiced on smaller scales, face challenges in implementing widespread agroforestry due to limited land availability and competing land-use demands. However, growing recognition of agroforestry's environmental benefits is driving policy support and adoption across the EU, contributing to more resilient and diversified agricultural systems (Mosquera-Losada et al., 2023)

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Table 8. Total surface, agricultural area and common agroforestry area by country. Common agroforestry (AF) area is reported in km² and kha = kilo hectares. Data are ordered with respect to Common AF area.

Country	Country area	Agricultural area (km^2)	Common AF area (km^2)	Common AF area (kha)
Spain	498,556	267,346	44,803	4,480
Italy	300,650	143,578	15,475	1,548
Portugal	88,786	39,511	10,686	1,069
France	548,942	309,312	10,525	1,052
Germany	357,661	189,900	10,447	1,045
Romania	238,368	135,701	9,035	903
Poland	311,941	175,573	6,814	681
Greece	131,759	56,390	5,452	545
Sweden	449,657	38,064	4,634	463
Bulgaria	110,994	58,334	4,556	456
Finland	337,523	26,417	4,056	406
Hungary	93,009	60,244	3,167	317
Czech Republic	78,873	42,309	2,677	268
Latvia	64,587	24,396	2,640	264
United Kingdom	244,545	141,639	2,490	249
Austria	83,945	30,719	2,131	213
Switzerland	41,286	14,310	1,894	189
Slovakia	49,024	21,723	1,521	152
Ireland	69,940	45,027	1,284	128
Denmark	43,171	30,045	1,073	107
Belgium	30,666	15,899	1,050	105
Croatia	56,516	22,344	998	100
Lithuania	64,897	37,066	933	93
Estonia	45,345	13,591	927	93
Cyprus	9,257	4,241	414	41
Netherlands	37,380	21,600	325	32
Slovenia	20,272	5,641	251	25
Luxembourg	2,596	1,278	182	18
Malta	314	142	3	0
Total	**4,410,460**	**1,972,337**	**150,443**	**15,044**

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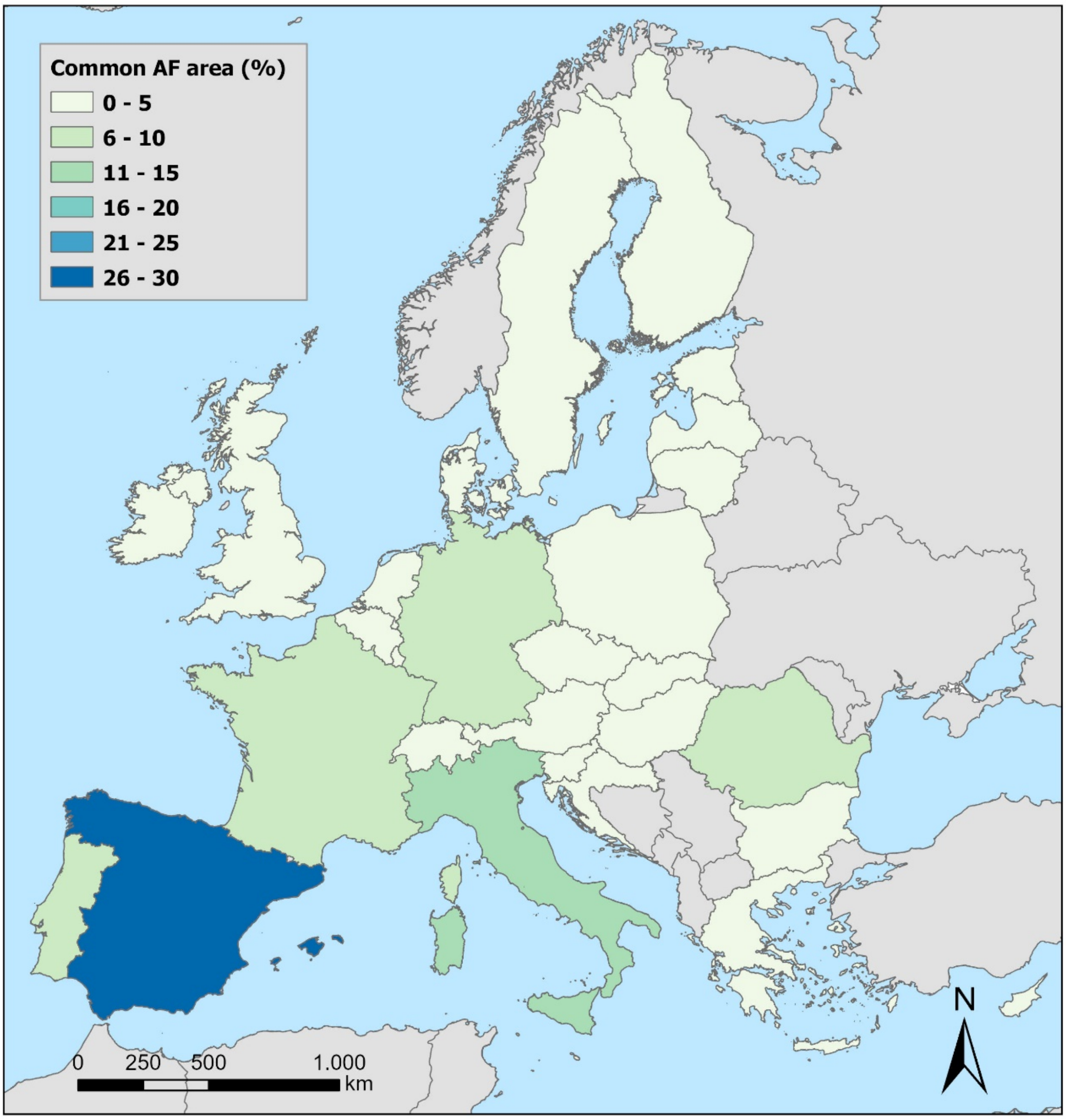

Figure 5. Percentage (%) of common agroforestry area relative to the total common agroforestry area by country.

Common agroforestry areas by biogeographical regions. Common agroforestry areas were most prevalent in the Mediterranean bioregion (Figure 6), accounting for 48% of the total, followed by the Continental bioregion with 26%, and the Atlantic bioregion with 8.4%. In contrast, the Pannonian (2.4%), Black Sea (0.2%), and Steppic (0.1%) regions had much lower proportions of agroforestry land (Table 9). The higher prevalence in the Mediterranean can be attributed to its long tradition of integrating trees with crops and livestock. The Continental and Atlantic regions also incorporate agroforestry, though to a lesser extent, as these bioregions tend to favour more intensive farming practices. Meanwhile, the Pannonian, Black Sea, and Steppic regions have limited agroforestry, likely due to their climatic conditions and agricultural systems being less conducive to tree cultivation alongside crops.

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Table 9. Common agroforestry area in km^2 and kilo hectares (kha) by biogeographical regions.

Biogeographical region	Area (km$^{2)}$	Area (kha)	Area (%)
Mediterranean	72,155	7,215	48.0
Continental	38,942	3,894	25.9
Atlantic	12,702	1,270	8.4
Boreal	12,550	1,255	8.3
Alpine	10,012	1,001	6.7
Pannioan	3,642	364	2.4
Black Sea	270	27	0.2
Steppic	164	16	0.1
Total	**150,437**	**15,044**	**100**

Common agroforestry areas in the Boreal and Alpine regions were relatively similar, accounting for 8.4% and 8.3% of the total, respectively. In the Boreal region, agroforestry practices were primarily concentrated in Sweden, Finland, and the Baltic countries, where the integration of trees with pasture or crops helps enhance biodiversity, manage soil health, and mitigate the challenges posed by cold climates and short growing seasons. In the Alpine region, agroforestry was found across various mountain ranges, including the Pyrenees, Alps, Scandinavian Peninsula, Carpathians, and other high-altitude areas in Europe (Figure 7).

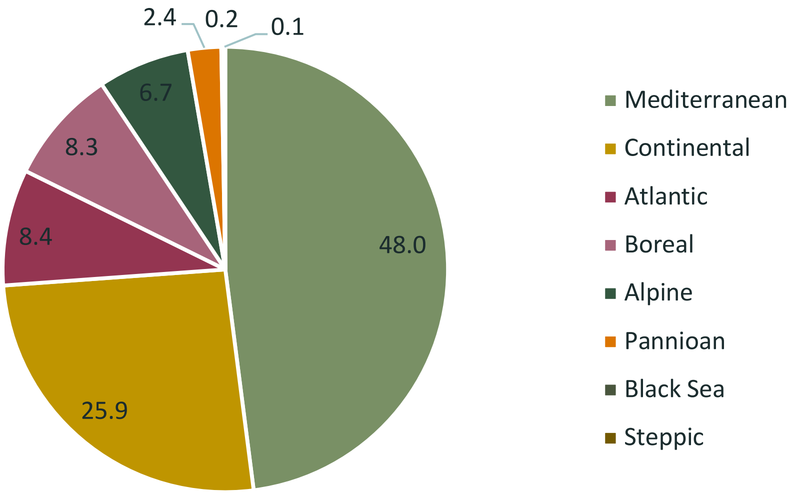

Figure 6. Share (%) of common agroforestry area relative to the total common agroforestry area by biogeographical region.

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The Alpine and Boreal regions often employ silvopastoral systems, where livestock graze under tree cover, helping prevent soil erosion on steep slopes while maintaining productive agricultural systems. The mountainous terrain and diverse microclimates of the Alpine region make agroforestry a valuable practice for maintaining ecological stability and agricultural sustainability, particularly in areas where conventional farming is less viable due to unfavourable environmental conditions. As climate change continues to affect both regions, agroforestry is increasingly recognised for its role in building climate resilience and promoting sustainable land management (Quandt et al., 2023; Terasaki Hart et al., 2023).

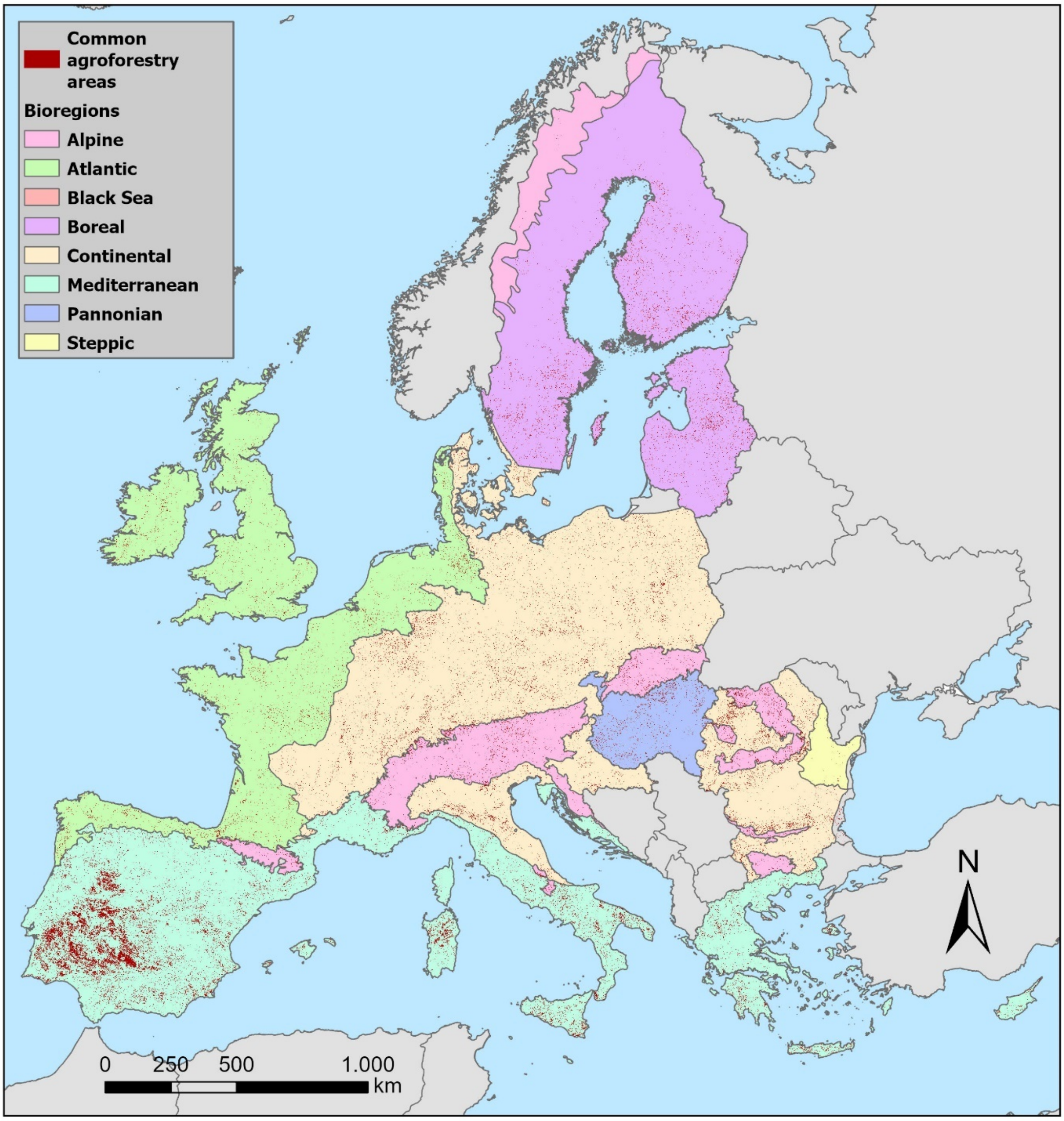

Figure 7. Spatial distribution of common agroforestry areas in the EU27 Member States, United Kingdom and Switzerland.

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Silvopastoral and silvoarable areas. More than 50% of the silvopastoral areas were concentrated in the Mediterranean regions, reflecting the long-standing tradition of integrating livestock grazing with trees in this climate. The Continental region followed with 20.3%, where silvopastoral systems are increasingly recognised for their potential to balance agricultural productivity and environmental sustainability. The Alpine region accounted for 8.8% of silvopastoral areas, where such practices are well-suited to mountainous landscapes, helping prevent soil erosion and supporting biodiversity in high-altitude environments (Table 10).

Table 10. Surface occupied by silvoarable and silvopastoral areas in each biogeographical region in the EU27, United Kingdom and Switzerland.

Bioregion	Silvoarable (km^2)	Silvoarable (%)	Silvopastoral (km^2)	Silvopastoral (%)
Mediterranean	21,038	39.2	43,550	58.6
Continental	16,283	30.4	15,075	20.3
Alpine	1,858	3.5	6,543	8.8
Atlantic	4,714	8.8	5,184	7.0
Boreal	7,839	14.6	2,532	3.4
Pannonian	1,698	3.2	1,247	1.7
Black Sea	112	0.2	110	0.1
Steppic	79	0.1	55	0.1
Total	**53,622**	**100.0**	**74,296**	**100.0**

Similarly, the Mediterranean region also dominated silvoarable systems, with 39.2% of such areas found there, followed by the Continental region with 30.4%. However, unlike silvopastoral areas, the Boreal region ranked third for silvoarable systems instead of the Alpine region. This difference may be due to the Boreal region's vast forest landscapes and growing interest in agroforestry practices to enhance soil health and improve land productivity in cold climates, where combining tree cover with crops can offer significant ecological benefits. These distinctions highlight how agroforestry practices vary across different bioregions based on local climate, landscape, and traditional farming methods (Figure 8).

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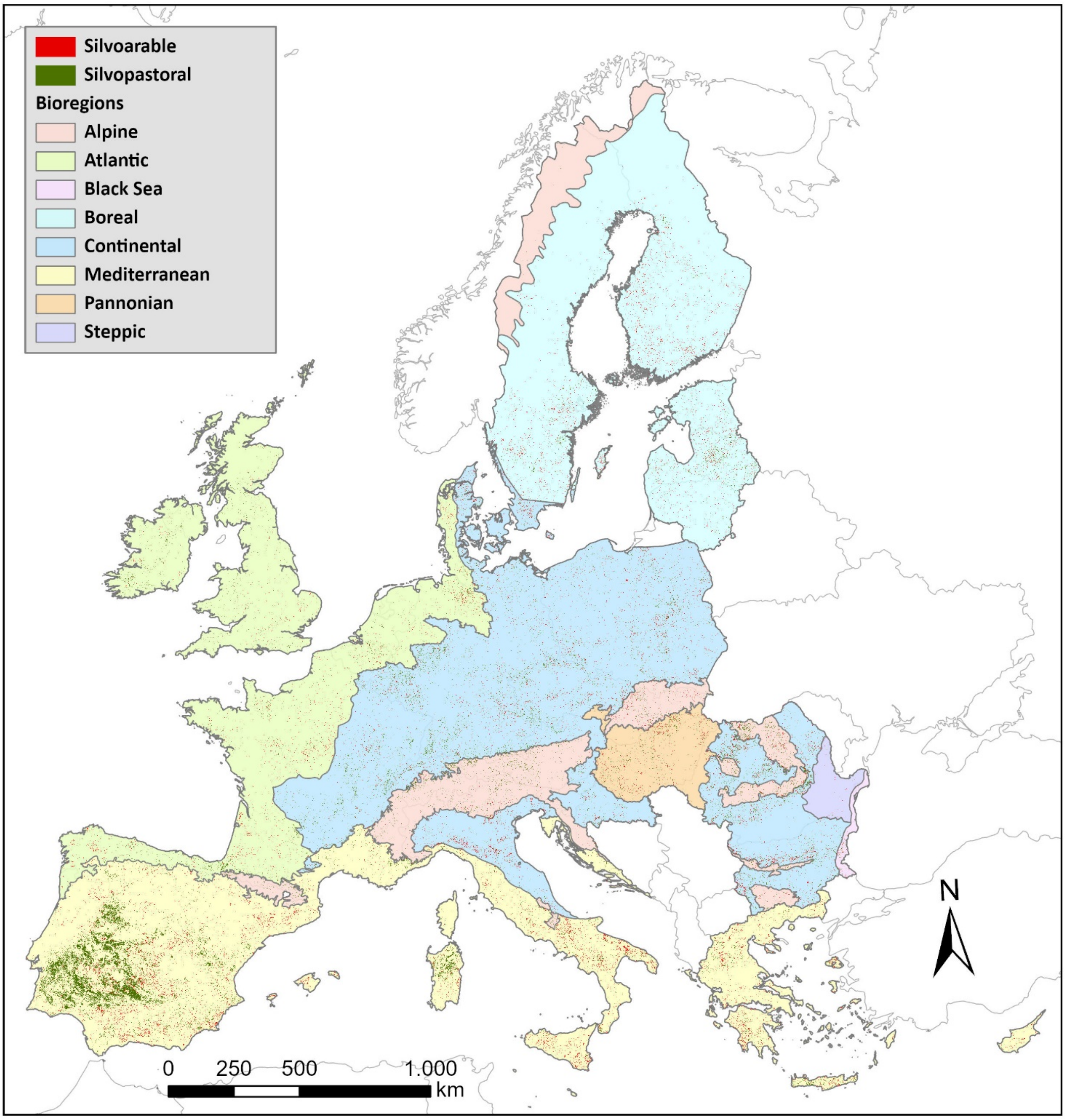

Figure 8. Spatial distribution of silvoarable and silvopastoral systems identified in the EU27, United Kingdom and Switzerland.

In terms of tree height within these systems, 75.5% of the canopy cover in silvopastoral systems and 57.4% in silvoarable systems was concentrated in the 1 to 5-meter range, primarily due to the dominance of shorter vegetation such as shrubs, young trees, and managed agricultural species. Smaller proportions of the canopy extended into the 5 to 10-meter range and above, where more mature trees or tall species contribute to the overall structure (Table 11). This distribution is likely influenced by land management practices, such as pruning and spacing, which aim to balance tree cover with crop or pasture productivity, ensuring optimal light penetration and resource availability for both trees and understory vegetation.

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Table 11. Area (%) in proportion to the total silvopastoral and silvoarable areas, falling into different canopy height classes, from 1 to more than 25 m.

Tree height (m)	Silvopastoral (km^2)	Silvopastoral (%)	Silvoarable (km^2)	Silvoarable (%)
1-5	15,777	75.5	7,705	57.4
5-10	3,334	16.0	3,212	23.9
10-15	1,213	5.8	1,677	12.5
15-20	460	2.2	673	5.0
20-25	107	0.5	144	1.1
>25	2	0.0	1	0.0
Total	**20,894**	**100.0**	**13,413**	**100.0**

Regarding the forest types identified within silvopastoral and silvoarable areas, the majority of the land was classified as non-forest, reflecting the agricultural nature of these systems, which are primarily focused on livestock or crop production rather than forestry. However, notable proportions of silvopastoral areas (36.5%) and silvoarable areas (18.8%) were characterised as broadleaved forest, likely due to the presence of tree species that enhance biodiversity, provide shade, or improve soil health. Small proportions of these systems also included coniferous and mixed forests, which may be present for timber production, windbreaks, or ecosystem services such as carbon sequestration. These forested areas contribute to the multi-functionality of the landscapes, supporting both agricultural productivity and environmental sustainability (Table 13).

Table 12. Area (%) in proportion to the total silvopastoral and silvoarable areas belonging to different forest type classes.

Class	Silvopastoral (%)	Silvoarable (%)
All non-forest areas	59.1	75.4
Broadleaved forest	36.5	18.8
Coniferous forest	1.8	2.4
Mixed zones	2.6	3.4

2.3.3.2 Small woody features agroforestry areas

Small woody features agroforestry areas by country. Significant small woody features areas were identified in France, Germany, Poland and United Kingdom (Figure 9), representing more than 20% of their total agricultural area. Conversely, in countries with large agricultural areas, such as Spain, Romania and Hungary, small woody features agroforestry represented less than 20% of their agricultural area (Table 14).

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Table 13. Total surface, agricultural area and small woody features agroforestry (SWFAF) area by country. Small woody features agroforestry area is reported in km^2 and kilo hectares (kha).

Country	Country area	Agricultural area (km2)	SWFAF area (km^2)	SWFAF area (kha)
France	548,942	309,312	101,535	10,154
Germany	357,661	189,900	44,560	4,456
Poland	311,941	175,573	42,879	4,288
United Kingdom	244,545	141,639	36,992	3,699
Italy	300,650	143,578	33,916	3,392
Spain	498,556	267,346	29,848	2,985
Romania	238,368	135,701	18,188	1,819
Ireland	69,940	45,027	16,092	1,609
Greece	131,759	56,390	12,681	1,268
Bulgaria	110,994	58,334	12,232	1,223
Sweden	449,657	38,064	11,797	1,180
Portugal	88,786	39,511	10,991	1,099
Czech Republic	78,873	42,309	10,409	1,041
Hungary	93,009	60,244	9,956	996
Austria	83,945	30,719	8,206	821
Denmark	43,171	30,045	7,792	779
Lithuania	64,897	37,066	7,606	761
Finland	337,523	26,417	7,415	742
Croatia	56,516	22,344	6,669	667
Latvia	64,587	24,396	6,419	642
Netherlands	37,380	21,600	5,070	507
Slovakia	49,024	21,723	5,018	502
Belgium	30,666	15,899	4,262	426
Estonia	45,345	13,591	3,961	396
Switzerland	41,286	14,310	3,351	335
Slovenia	20,272	5,641	2,331	233
Cyprus	9,257	4,241	504	50
Luxembourg	2,596	1,278	228	23
Malta	314	142	34	3
Total	**4,410,460**	**1,972,337**	**460,944**	**46,094**

Comparing the proportion of small woody features agroforestry and the proportion of common agroforestry areas to the total agricultural area by country, in Slovenia, Ireland, France and Croatia more than 25% of their agricultural area corresponded to small woody features agroforestry, but less than 5% were common agroforestry area. Countries with similar proportions of small woody features and common agroforestry areas, in proportion to their agricultural land, were Spain, Portugal, Cyprus and Luxembourg with differences in these proportions below 5%.

In absolute terms of the total agroforestry areas identified in Europe, differences between reported common agroforestry and small woody features agroforestry areas were observed in Spain, where the extent of

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common agroforestry areas was notably higher compared to the surface occupied by small woody features agroforestry. On the other hand, the extent of small woody features agroforestry was larger in France in regards with the common agroforestry areas.

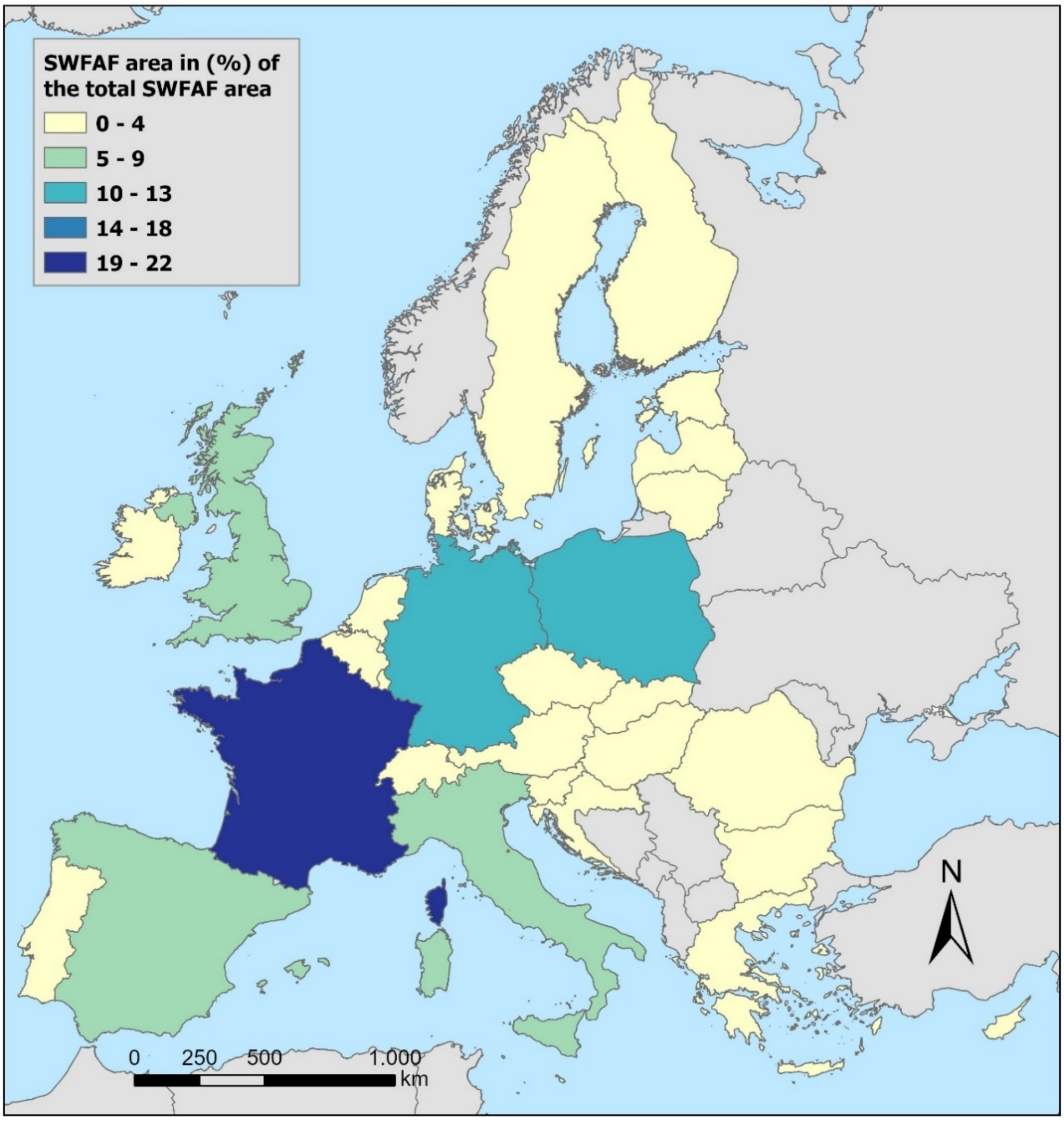

Figure 9. Percentage (%) of small woody features agroforestry (SWFAF) area relative to the total small woody features agroforestry area by country.

Small woody feature agroforestry areas by biogeographical regions. More than 60% of the small woody features in agroforestry areas were identified within the Continental and Atlantic biogeographical regions (Table 15), largely due to the higher concentrations of these features in countries like France and Ireland (Figure 11). These regions are characterised by suitable climatic conditions, such as moderate rainfall and temperature, which support the growth of hedgerows, shelterbelts, and other small woody elements. These features play a critical role in landscape connectivity, biodiversity conservation, and the provision of ecosystem services such as soil stabilisation and microclimate regulation.

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Table 14. Small woody features agroforestry area in km² and kilo hectares (kha) by biogeographical regions.

Biogeographical region	Area (km^2)	Area (kha)	Area (%)
Continental	173,770	17,377	37.7
Atlantic	139,213	13,921	30.2
Mediterranean	77,399	7,740	16.8
Boreal	35,132	3,513	7.6
Alpine	20,141	2,014	4.4
Pannonian	13,229	1,323	2.9
Steppic	1,296	130	0.3
Black Sea	674	67	0.1
Total	**460,854**	**46,085**	**100.0**

In the Mediterranean region, small woody features in agroforestry accounted for a substantial proportion, comprising 16.8% of the total. This was followed by the Boreal (7.6%) and Alpine (4.4%) bioregions, where these systems were less prominent but still notable. In contrast, small woody features in agroforestry were less common in the Pannonian, Steppic, and Black Sea regions, where they represented only 3.3% of the total agroforestry systems (Figure 10).

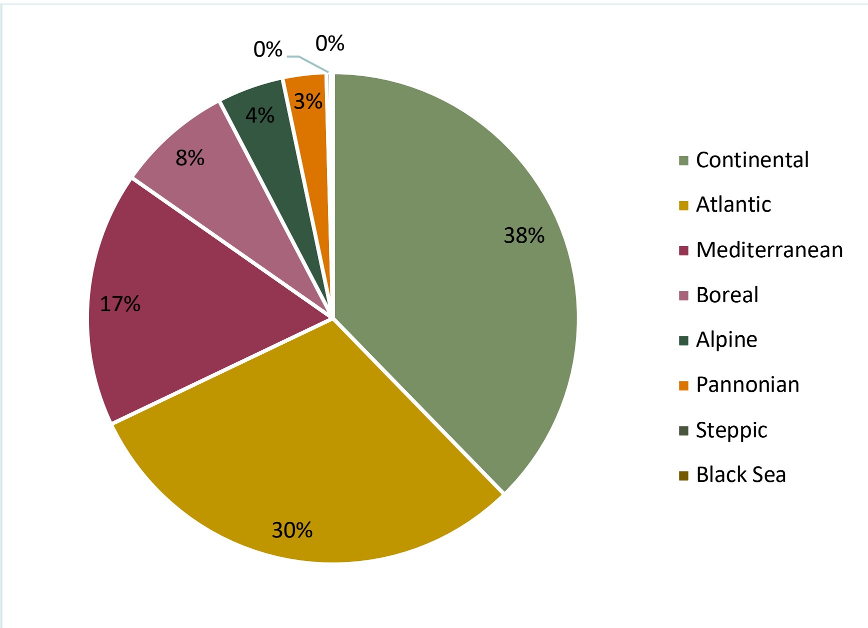

Figure 10. Share (%) of small woody features agroforestry area relative to the total small woody features agroforestry area by biogeographical region.

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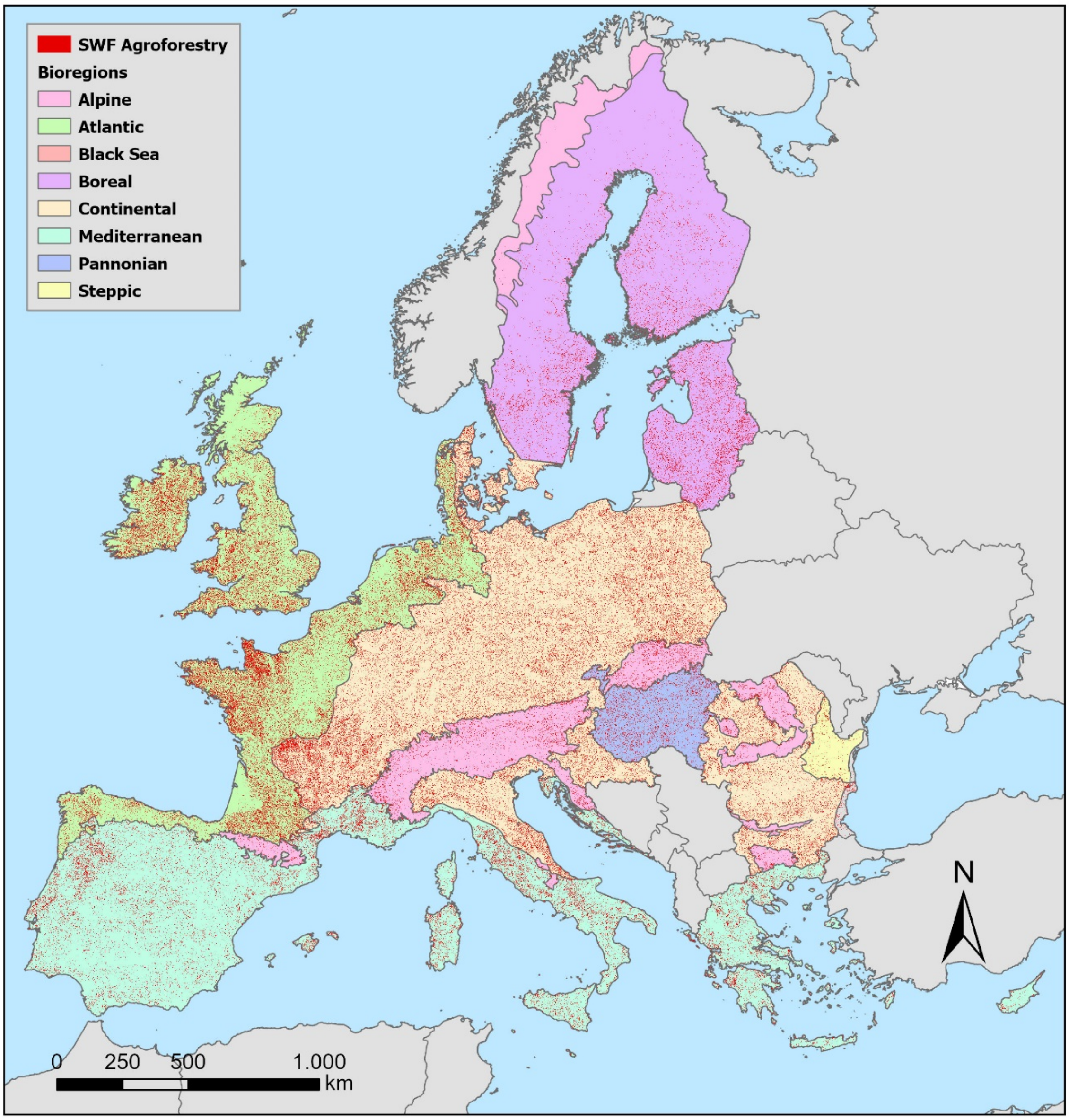

Figure 11. Spatial distribution of small woody features agroforestry in the EU27 Member States, United Kingdom and Switzerland.

2.3.3.3 Tree height and forest type in agroforestry areas

Canopy height values in approximately 60% of both common agroforestry and small woody features agroforestry areas ranged between 1 and 5 meters (Table 16). However, canopy height in small woody features agroforestry was generally lower compared to common agroforestry areas. This is because common agroforestry systems typically include taller trees, while small woody features are associated with shrubs, hedgerows, and smaller-sized woody elements. In common agroforestry areas, 23.2% of the land had trees taller than 10 meters, whereas in small woody features, only 12.8% of the area reached this height.

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Table 15. Area (%) in proportion to the total common agroforestry and small woody features agroforestry (SWFAF) area falling into different tree height classes, ranging from 1 to more than 25 m.

Tree height (m)	Common AF (km^2)	Common AF (%)	SWFAF (km^2)	SWFAF (%)
1-5	27,567	56.5	74,184	58.6
5-10	9,953	20.4	36,201	28.6
10-15	6,273	12.9	12,672	10.0
15-20	3,788	7.8	3,345	2.6
20-25	1,219	2.5	277	0.2
>25	19	0.0	6	0.0
Total	**48,819**	**100.0**	**126,684**	**100.0**

Regarding forest type, most agroforestry systems, particularly small woody features agroforestry, are predominantly found in agricultural areas outside forests. These systems often thrive in open landscapes where trees, hedgerows, and other woody vegetation provide key ecosystem services like windbreaks, biodiversity corridors, and soil stabilisation. However, a smaller proportion of small woody features agroforestry (10.8%) is found in broadleaved forests, with minor occurrences in mixed (0.6%) and coniferous (0.6%) forests (Table 16), likely due to their role in enhancing biodiversity and supporting sustainable land management in these environments.

Common agroforestry areas are more integrated with forested landscapes, with nearly one-third occurring in broadleaved forests. These forests, often characterised by open canopies, support the integration of productive activities such as grazing or silvopastoral. Smaller proportions are found in mixed (4.1%) and coniferous (3.9%) forests (Table 17), suggesting that agroforestry practices can adapt to various forest types depending on specific conditions like soil, elevation, and climate. Broadleaved forests provide favourable conditions for combining agriculture and forestry.

Table 16. Area (%) in proportion to the total common agroforestry and small woody features agroforestry area (SWFAF) belonging to different forest types (all non-forest areas, broadleaved forest, coniferous forest and mixed zones).

Class	Common agroforestry (%)	SWFAF (%)
All non-forest areas	60.7	87.2
Broadleaved forest	31.3	10.8
Coniferous forest	3.9	0.6
Mixed zones	4.1	1.4

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3 The impacts of silvopastoral and silvoarable agroforestry systems on the LULUCF carbon inventory

Salim Edris and Rodrigo Olave, Agri-food and Biosciences Institute (AFBI)

3.1 Overview

This section aims to I) estimate potential biomass carbon removal rates, II) quantify soil organic carbon stock and identify management activities that could potentially emit GHGs and III) assess the possible impacts of the identified silvopastoral and silvoarable agroforestry systems on the EU's LULUCF inventory. The approach used consists of the following steps: 1) selecting a specific area within the mapped area of previous section based on the available inventory activity data, 2) analysing tree biomass carbon removal rates, 3) estimating the potential SOC of soils occupied by silvopastoral and silvoarable agroforestry systems as well as identifying management activities, and 4) quantifying the impact of agroforestry systems on LULUCF inventory. These analyses are only carried out for silvopastoral and silvoarable systems as defined in Table 1. Furthermore, the spatial distribution and surface areas used in this section are the ones determined in section2.

3.2 Methodology

3.2.1 Selected agroforestry areas

Only areas of silvopastoral and silvoarable systems which fall within the three main biogeographical regions Atlantic, Continental and Mediterranean (EU3bR) were selected from the previous analysis, Section 2, to estimate their impacts on the LULUCF carbon inventory. This is due to the limited data availability of biomass carbon removal data, which were obtained from EURAF carbon farming dataset that covers only part of mapped area. For further analysis e.g., identifying climate-soil zones (see 3.3.4.3), the raster maps of the selected agroforestry systems were then converted into vector, shapefiles, format.

3.2.2 Carbon removal rates of agroforestry systems

Identifying the carbon removal potentials and rates of silvopastoral and silvoarable systems is crucial for quantifying the total biomass carbon removal potentials of the selected areas. In this part, the European Agroforestry Federation (EURAF) carbon framing dataset (Gerry et al., 2020) was used to quantify carbon sequestration rates of the selected systems (Figure 12).

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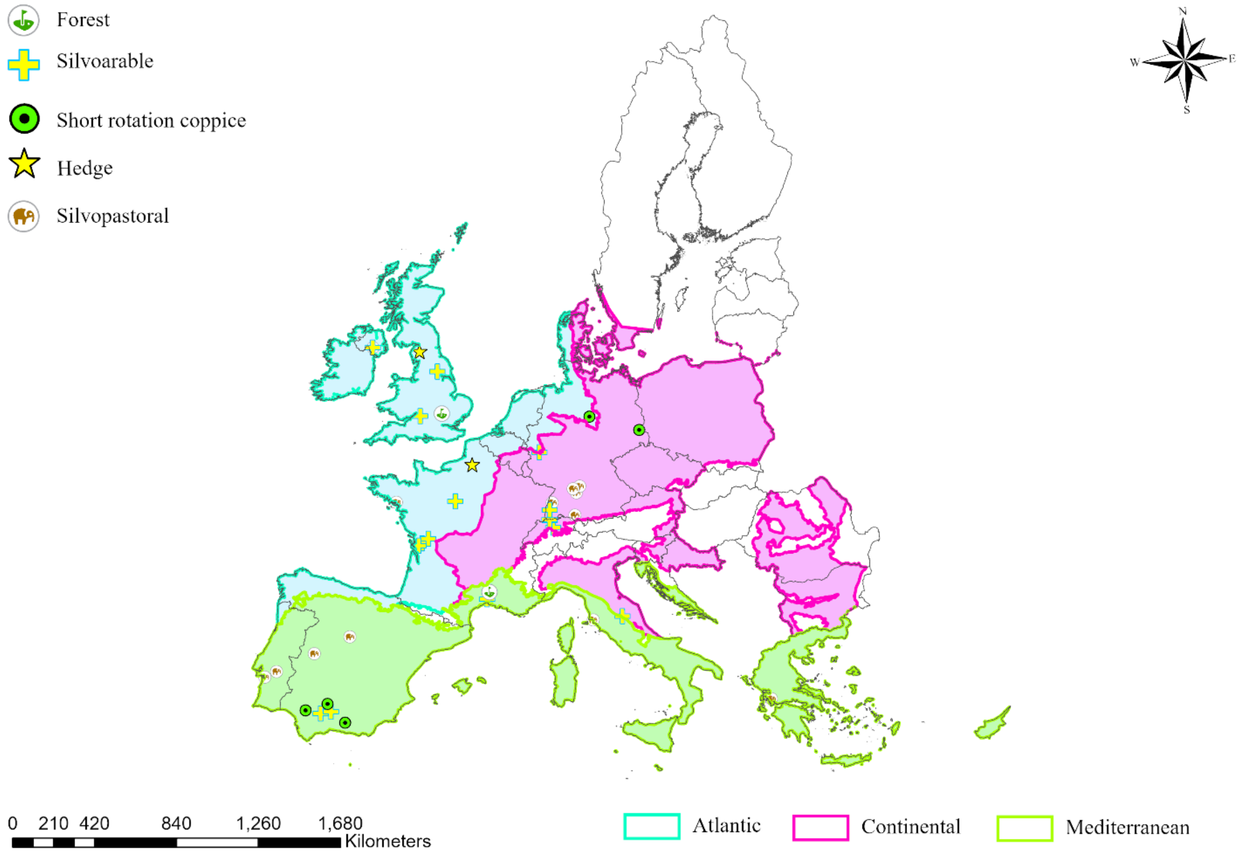

Figure 12. EURAF carbon farming dataset (Gerry et al., 2020)

The dataset encompasses empirically derived tree biomass carbon removal values for tree species implemented in diverse agroforestry practices, including hedges, short-rotation coppices, silvoarable systems, and silvopastoral systems.

Data pertinent to Atlantic, Continental, and Mediterranean European bioregions were extracted from the dataset and augmented with carbon removal rates for ash and poplar trees recorded in Loughgall, Northern Ireland. Only removal rates related to silvopastoral and silvoarable systems within the selected area (EU3bR) were considered. Subsequently, the established default values from the 2019 Intergovernmental Panel on Climate Change (IPCC) guidelines were utilised to compute below-ground biomass carbon sequestration rates and an assumption of 25% of below-ground to above-ground was considered for all regions (Domke et al., 2019) .

3.2.3 Potential soil organic carbon (SOC) stock in agroforestry systems

Silvopastoral and silvoarable areas identified in section 2.2.4 and selected in section 3.3.1 were used as the main activity data then stratified by climate-soil regions identified in section 3.3.4.3. Where factors such as standard SOC (SOC_{ST}), land use (F_{LU}), managements (F_{MG}), and input (F_{I}) factors were identified based EU commission decision of 10 June on guidelines for calculation of land carbon stock, which is based on 2006 IPCC guidelines (EU, 2010; Rodel Lasco et al., 2006). The selection of the appropriate factors was based on

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Loughgall case assuming that the condition in which soil organic carbon stock in a grazed grassland is being estimated is equivalent to in silvopastoral area using equation 1. Similarly, cropland equivalent to silvoarable systems using the same equation. Since the area of organic soils within the selected area is less than 2%, only SOC of mineral soils were considered.

$$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_{I} \quad (1)$$

Where:

SOC = soil organic carbon (measured as mass of carbon per hectare).

SOC_{ST} = standard soil organic carbon in the 0–30-centimeter topsoil layer (measured as mass of carbon per hectare);

F_{LU} = land use factor reflecting the difference in soil organic carbon associated with the type of land use compared to the standard soil organic carbon.

F_{MG} = management factor reflecting the difference in soil organic carbon associated with the principal management practice compared to the standard soil organic carbon.

F_{I} = input factor reflecting the difference in soil organic carbon associated with different levels of carbon input to soil compared to the standard soil organic carbon.

3.2.4 Potential emissions from agroforestry systems - UK, Loughgall and Spain, Majadas

AFBI, Loughgall (UK) and Majadas de Tietar in (Spain) agroforestry sites were considered to identify the relevant management activities which could potentially emit greenhouse gases. The UK site is located in a cool temperate Atlantic region while the Spanish site is located in a warm temperate Mediterranean region. Only silvopastoral and silvoarable agroforestry systems were evaluated and the appropriate emission factor values were obtained from 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

3.2.4.1 Site 1 description - AFBI Loughgall site, UK

This site is located at (lat 54.4° N, long 6.6° W), Agri-Food and Biosciences Institute (AFBI) research centre in Loughgall, County Armagh, Northern Ireland, UK, approximately 35 m above sea level. It was established in 1989 as part of the UK National Network Experiments (NNE).

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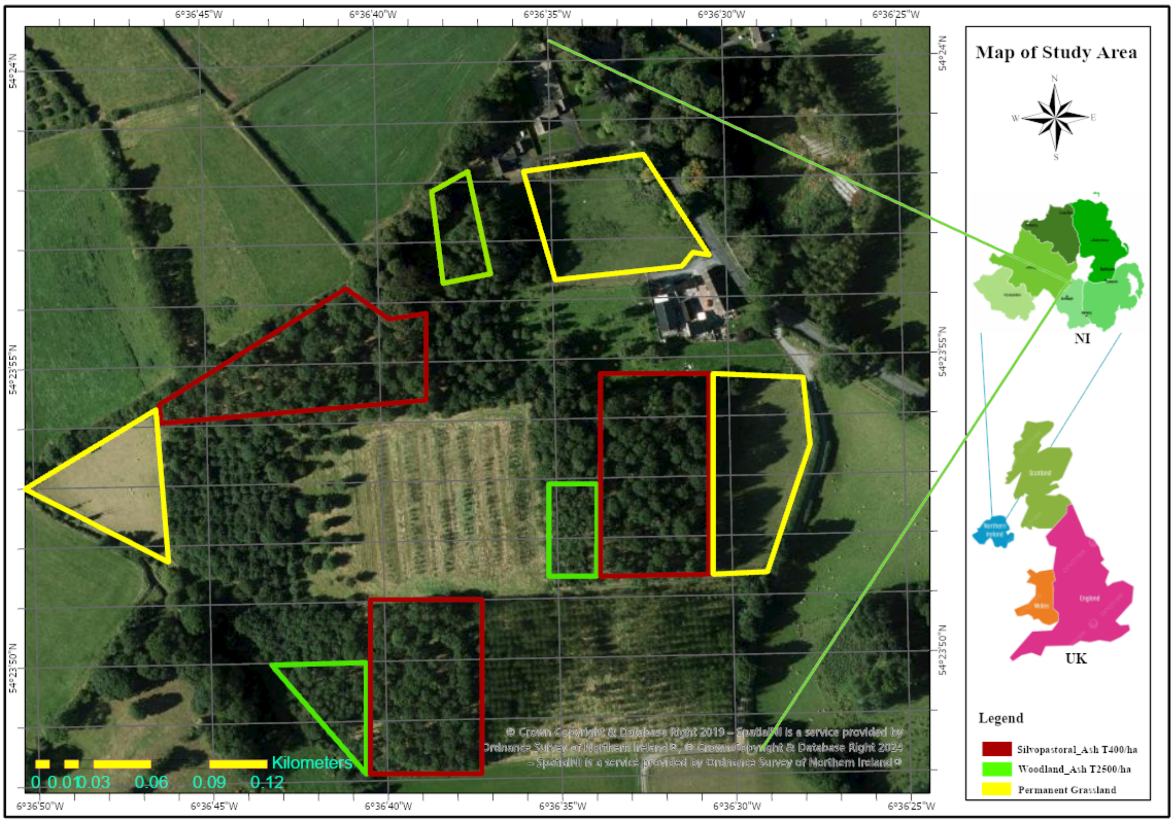

Figure 13. Map of Loughgall NNE experimental site

The silvopastoral system in this site (Figure 13) includes 3 replications of 3 land uses; I) silvopastoral system with ash trees (*Fraxinus excelsior L.*), II) woodland planted with ash trees, and III) permanent grassland.

The silvopastoral and woodland plots were originally planted at 400 stems ha^{-1} (5 x 5 m spacing) and 2500 stems ha^{-1} (2 x2 m spacing) respectively. The silvopastoral plots density was reduced with thinning to 265 stems ha^{-1} in 2004, to 170 stems ha^{-1} in 2009 and then to only 138 stems ha^{-1} with the stumps remaining in the ground. The woodland plots received minimal management except for thinning and pruning which were applied in 2009 to improve the quality of the trees, reducing tree density to an average of 1100 stem ha $^{-1}$. In the period between 1989 and 2024 fertiliser application occurred at rates of 160 and 50 kg N ha^{-1} year^{-1} in silvopastoral and grassland plots. Sheep grazing at the rate of 12 ewes ha^{-1} occurred from April to November of each year in both grassland and silvopastoral plots.

The first pruning (removing a portion of tree branches to enhance the tree's heath and shape) in the silvopastoral plots took place in 1998 and was repeated every three years until 2022. This practice involves. Approximately 10-15% of both large and small branches were typically removed during each pruning. In 2020, the average DBH (diameter at breast height) of ash trees in the silvopastoral and woodland plots were 33.33 and 21.9 cm with average stand heights of 17.62 and 19.17 m respectively (Fornara et al., 2017).
This site also includes a silvoarable system established in 1993. This system consists of single plot planted with four species of poplar tree and inter-row barley (*Hordeum vulgare vulgare L.)* until 2003 then replaced by grass crop in the years afterward. The initial tree density was 142 trees per hectare with a spacing of 5

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meters by 12 meters. No thinning or pruning activities have been implemented since the systems was established.

3.2.4.2 Site 2 description - Majadas de Tietar, Spain

This site is located at (latitude 39.5 N, longitude 5.4° W) in the centre of the Iberian Peninsula, province of Caceres, Spain (Casals et al., 2009, Perez-Priego et al., 2017). It is a tree-grass ecosystem with an average of a typical "*Iberian dehesa*," with 20–25 *Quercus ilex* trees $ha^{-1,}$ and a canopy height of 8.7 meters. The site is a managed and used for extensive cattle farming with a stocking rate of $\leq$ 0.3 ha^{-1} where the cattle grazing takes place between June to December each year. Mean annual precipitation and temperature are 636 mm and 16.7° C, for the period from 2004 to 2009 (Perez-Priego et al., 2017).

3.2.4.3 Selected management activities and processes within silvopastoral and silvoarable systems with potential GHG emissions.

There are numerous activities and processes within such land use systems that have the potential to release GHG emissions. These include **pre-farm** activities (e.g., fertiliser production, storage, and transportation of production inputs) and **on-farm** activities and processes (e.g., machinery operation, thinning, pruning, harvesting, grazing, power supply, enteric fermentation, and manure management).

Herbivorous ruminant livestock (e.g., cattle, sheep) release methane (CH_4), as a by-product via a digestive process known as enteric fermentation by which carbohydrates are broken down by micro-organism into simple molecules for absorption into the bloodstream. The amount of methane released depends on the digestive systems and feed intake (Hatfield et al., 2006) .
Thinning is the practice of removing some trees to improve the quality of the remaining trees. Pruning involves selectively removing parts of a plant, such as branches, leaves, or roots, to enhance its health, shape, and productivity (Skovsgaard et al., 2021). The woody material removed by these practices is often used as firewood, which, when burned, releases GHGs, including carbon dioxide (CO_2).
Fertilisation is the process of adding synthetic or organic fertilisers to increase soil fertility and maintain or improve production. Fertilisers typically contain nitrogen (N), phosphorus (P), and potassium (K), which are essential elements for most crops. Increasing the availability of nitrogen in the soil can enhance nitrification and denitrification rates, leading to increased direct emissions of nitrous oxide (N_2O) (De Klein et al., 2006; Gao & Cabrera Serrenho, 2023).

Harvesting is a common practice in silvoarable systems, where annual or perennial crops are cultivated. These crops store carbon in their biomass. However, under the Tier 1 methodology, it is assumed that the biomass gained in a single year is equal to the biomass lost from harvesting and mortality in the same year (Rodel Lasco et al., 2006). This implies that all the carbon removed by biomass is eventually emitted, making harvesting a contributor to emissions. A similar principle applies to grazed silvopastoral systems, where the carbon removed and stored in the grown grass is lost through grazing (Krug et al., 2006).

Under Tier 1, only one emission factor was considered: the portion of directly emitted N_2O due to the application of synthetic fertilisers (De Klein et al., 2006). Emissions related to crop residues, drained soils and animal excreta were omitted from the estimation of emissions from silvopastoral systems due to their irrelevance and lack of data.

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Due to limitation of data availability, only the following on-farm management activities and processes were considered to estimate their potential GHG emissions using 2006 and 2019 IPCC emission factor default values:

Thinning
Pruning
Fertilisation
Grazing
Harvest
Grazing
Enteric fermentation

3.2.5 Potential impact of silvopastoral and silvoarable systems on LULUCF carbon inventory

Removals and emissions data related to Land use, Land Use Change and Forestry (LULUCF) sector plus Agriculture were gathered from the submitted national inventory reports (NIRs) and common reporting formats' (CRFs) of European Union + UK and Switzerland. NIRs and CRFs are detailed reports submitted by counties to the secretariat of the (UNFCCC) United Nations Conventions on Climate Change (UNFCCC, 2022). These reports provide comprehensive data on GHG emissions and removals across various sectors within a country. The relevant data were gathered from baseline 1990 to 2020 and the mean and changes were calculated to highlight the impact of the silvopastoral and silvoarable agroforestry systems on LULUCF's sector inventory.

3.3 Results

3.3.1 Selected study area

The EU3bR regions collectively cover approximately 2.91 million km^2 or almost 67.9 % of EU-28 territorial area. The Continental bioregion has the largest extent, occupying 29.4% of EU 28 territorial area, followed by Mediterranean and Atlantic 20.7 and 17.9% respectively (Susanne Schnabel et al., 2020). Around 34% of the Atlantic region within the selected area is occupied by France, 30% by UK followed by Germany, Republic of Ireland and Spain representing around 9, 8 and 7% respectively (Figure 14). Approximately 23% of Continental bioregion area falls within Poland and around 21% in Germany followed by France, Romania and Italy, which represent roughly 14, 10 and 6% respectively. Approximately 50% of Mediterranean area is covered by Spain while around 17, 13 and 9% of the area is located in Italy, Greece and Portugal respectively (Figure 14).

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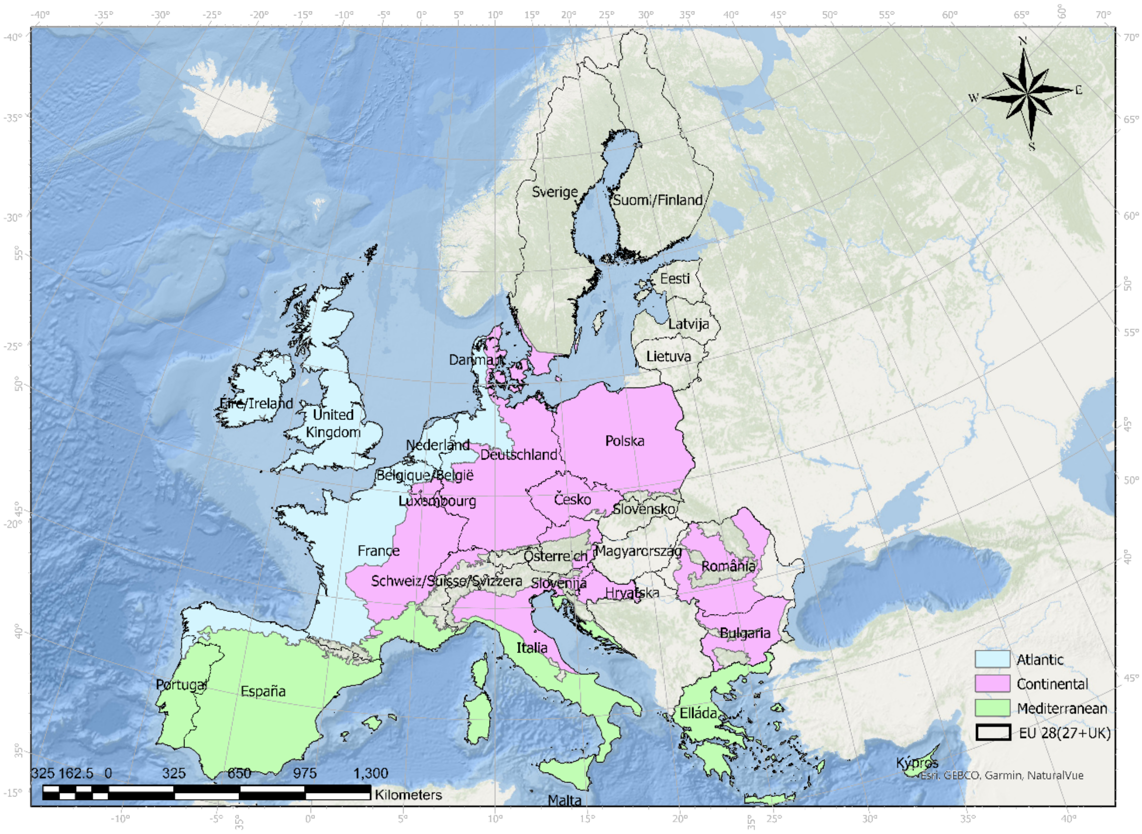

Figure 14. EU main bioregions (Atlantic, Continental and Mediterranean)

Based on the agroforestry areas reported in the previous section, the agroforestry areas were clipped to include only areas within EU3bR and desired classes, silvopastoral and silvoarable agroforestry areas.

3.3.2 Silvopastoral and silvoarable areas within the selected regions.

Generally, only around 10.2 million ha (Mha) of agroforestry areas were considered for carbon inventory analyses, which is 3.5% less than silvopastoral and silvoarable surfaces areas (10.5 Mha) presented previously in Section 2, (Table 10). This difference occurred due to the conversion of maps from raster to vector format, which was necessary for further analyses. In terms of overall distribution, silvopastoral systems constitute most agroforestry practices, covering 6.2 Mha, which accounts for 61.31% of the total common agroforestry areas. Silvoarable systems cover 3.9 Mha, representing 38.69% of the total. The total agroforestry area across the selected areas is 10.2 Mha, which represents 3.50% of the total land area of the regions analysed, see Table 17.

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Table 17. Silvopastoral and silvoarable areas in the selected region

Agroforestry systems	Atlantic		Continental		Mediterranean		EU3bR	
	Agroforestry area in Kha and their percentage in different bioregions							
	area	%	area	%	area	%	area	%
Silvopastoral	466.43	52.62	1379.82	48.36	4411.30	68.21	6257.55	61.31
Silvoarable	419.93	47.38	1473.33	51.64	2056.05	31.79	3949.31	38.69
Total	886.36	100.00	2853.15	100.00	6467.35	100.00	10206.86	3.50
Total regions area	74907.76	1.18	126856.50	2.25	89807.28	7.20	291571.54	100

In terms of bioregions, the Atlantic has a total agroforestry area of 886.36 Kha with 466.43 Kha (52.62%) occupied by silvopastoral systems, while 419.93 Kha (47.38%) is used for silvoarable systems. The total area of the Atlantic region is 74907.76 Kha, with these agroforestry systems accounting for 1.18% of this area. In the Continental bioregion, the total agroforestry area is significantly larger at 2.8 M ha (Figure 15).

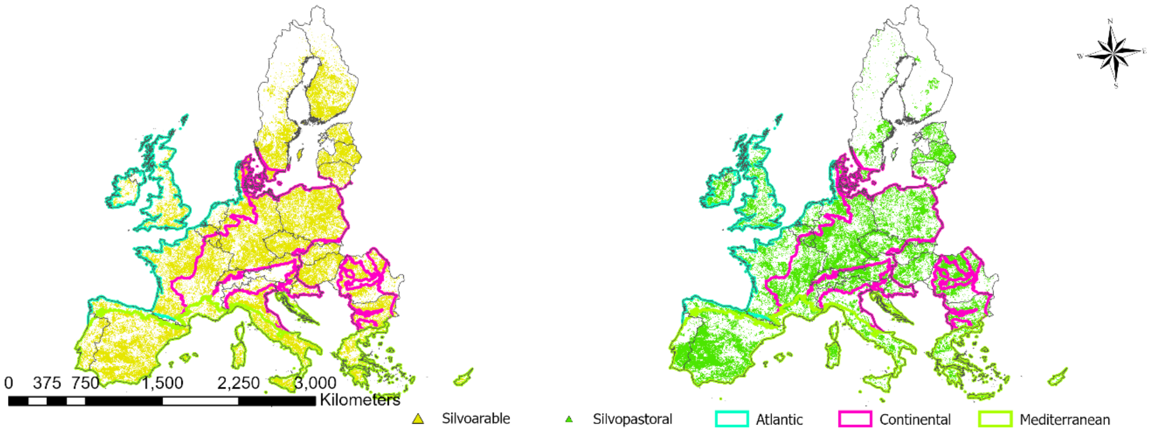

Figure 15. Classified silvopastoral and silvoarable agroforestry areas based on results obtained in section 2

Silvopastoral systems cover 1.3 M ha or 48.36%, while silvoarable systems cover 1.4 M ha or 51.64%. Where the region has a total area of 126.8 M Kha, with agroforestry practices making up 2.25% of this area. Whereas the Mediterranean stands out with the largest total agroforestry area of 6.4 M ha in this region, silvopastoral systems are predominant, covering around 68.21%, while silvoarable systems account for 31.79%.

3.3.3 Carbon removal rates of silvopastoral and silvoarable agroforestry areas

To estimate the biomass carbon removal rates of the silvopastoral and silvoarable areas within the selected area, tree biomass carbon removal rates obtained from EURAF carbon farming data were used to calculate the total carbon removal rates of these land use systems as of 2018.

3.3.3.1 Tree biomass carbon removal rates – EURAF carbon farming dataset

This analysis assesses potential carbon removal rate (t C ha^{-1} yr^{-1}) of silvopastoral and silvoarable systems across three bioregions: Atlantic, Continental, and Mediterranean. Table 18 provides a comparative analysis

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of potential removal rates across three different bioregions. Carbon removal rates were assessed in terms of above-ground biomass carbon (A-GBC) and below-ground biomass carbon (B-GBC). The result highlights both the overall performance of these systems and the specific contributions of various tree species within these systems.

Table 18. silvopastoral and silvoarable biomass carbon removal rates

Af systems		Atlantic			Continental			Mediterranean		
		t C ha^{-1} Yr^{-1}								
		A-GBC	B-GBC	Mean	A-GBC	B-GBC	Mean	A-GBC	B-GBC	Mean
	Silvopastoral			**3**			**3.21**			**2.69**
Silvopastoral	Fruit Trees	1.76	0.44	2.20						
	Ash	2.50	1.30	3.80						
	Poplar				2.57 ± 2.01	0.64	3.21	5.68 ± 4.82	1.42	7.10
	Oak							2.36 ± 2.20	0.59	2.95
	Olive							0.38 ± 0.27	0.10	0.48
	Conifer							0.20	0.05	0.25
	Silvoarable			**3.83**			**0.78**			**1.8**
Silvoarable	Poplar	5.51 ± 0.30	1.38	6.89	1.59	0.40	1.99	3.81	0.95	4.76
	Nut Trees	0.62	0.16	0.78	0.18 ± 0.21	0.05	0.23	1.31 ± 0.76	0.33	1.64
	Fruit Trees				0.10 ± 0.21	0.03	0.13			
	Olive							0.60 ± 0.39	0.15	0.75
	Almond							0.04	0.01	0.05

3.3.3.1.1 Mean tree biomass carbon removal rates of silvopastoral systems

Silvopastoral systems, which integrate trees with pasture or livestock, show significant removals rates across all bioregions. The highest removal rate for silvopastoral systems recorded in Continental bioregion, followed by the Atlantic and Mediterranean bioregions, 3.21, 3.0 and 2.69 t C ha^{-1} yr^{-1} respectively. In the Atlantic bioregion, ash trees have rate of 3.80 t C ha^{-1} yr^{-1}, while fruit trees and poplar contribute 2.20 and 3.21 t C ha^{-1} yr^{-1}, respectively. The Continental bioregion shows significant contributions from poplar, oak and olive, 3.21, 2.95 and 0.48 t C ha^{-1} yr^{-1} trees. In the Mediterranean bioregion, poplar species show removal rates of 7.10 t C ha^{-1} yr^{-1}, with ash and olive contributing 2.95 t and 0.48 t C ha^{-1} yr^{-1} respectively.

3.3.3.1.2 Mean tree biomass carbon removal rates of silvoarable systems

Silvoarable systems, which combine trees with crops, exhibit varying sequestration rates across the bioregions, with the highest potential observed in the Atlantic bioregion. In this bioregion, poplar trees demonstrate a significant rate of 6.89 t C ha^{-1} yr^{-1}, while nut trees and fruit trees contribute 0.78 and 0.13 t C ha^{-1} yr^{-1}, respectively. The Continental bioregion shows a lower overall sequestration potential, with poplar, nuts and fruit trees recording 1.99 t, 0.23 and 0.13 t C ha^{-1} yr^{-1} respectively. In the Mediterranean bioregion, poplar remains the most significant contributor with a potential sequestration rate of 4.76 t C ha^{-1} yr^{-1},

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followed by nut and fruit trees at 1.64 and 0.75 t C ha^{-1} yr^{-1}. Olive trees in this system show a minimal rate of 0.05 t C ha^{-1} yr^{-1}.

The data indicates that both silvopastoral and silvoarable systems have substantial carbon removals, with notable differences between bioregions and tree species. Silvopastoral systems generally show higher carbon storage potential in the Continental bioregion, while silvoarable systems are more effective in the Atlantic bioregion. Among individual tree species, poplars consistently demonstrate the highest sequestration rate across all bioregions and systems.

Results (Table 19) indicate the silvopastoral systems have higher tree density and older trees across all bioregions compared to silvoarable systems, particularly in the Mediterranean, where the measured systems both contain mature trees and higher density. This justifies the greater carbon removal rates in the silvopastoral systems due to the higher biomass accumulation linked with older and more trees. On the other hand, silvoarable systems, while still contributing to carbon removal, show a lower rate since they are relatively younger with less dense tree population per unit area.

Table 19. Mean tree density (D) and their age in the systems

Systems	Atlantic		Continental		Mediterranean		Mean	
	D	age	D	age	D	age	D	age
Silvopastoral	174	26	162	39	156	68	164	45
Silvoarable	124	19	126	18	92	18	114	18
Mean	149	22	144	29	124	43	139	31

3.3.3.2 The total tree biomass carbon removal rates of the selected study area

This analysis is central for understanding the role of agroforestry in sequestering carbon as it highlights the potential of these systems to contribute significantly to reducing atmospheric carbon levels, if current growth rates are maintained, or if additional trees are planted. It assumes that the agroforestry areas selected in Section 3.3.2, areas in 2018, have the same the carbon removal rates analysed in section 3.3.3.1 will continue unchanged up until 2030.

3.3.3.2.1 Annual tree biomass carbon removals rates of agroforestry areas

Table 20 presents an analysis of biomass carbon removal rates in various agroforestry systems across the selected bioregions. The data are derived from multiplying the biomass carbon removal rates (section 3.3.3.1) by the corresponding areas selected in section 3.3.2.

In general, the total annual biomass carbon removal rate in 2018 was approximately 88.66 Mt CO_2 with silvopastoral and silvoarable systems contributing by 64.95 and 23.70 Mt CO_2 respectively. The Mediterranean bioregion stands out as having the highest potential, as it has the largest areas of these systems with the highest removal rates.
Silvopastoral systems, which combine forestry with livestock grazing, show varying levels of carbon removal potential across the three bioregions. In the Atlantic bioregion, the annual removal rate is around 5.13 Mt CO_2 while Continental bioregion shows a higher removal rate. In contrast, the Mediterranean bioregion,

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however, has the highest potential, with a removal rate of 43.56 Mt CO_2, representing around 67% of total silvopastoral systems' removals.

Table 20. Agroforestry biomass carbon removal potentials in 2018 and 2030

Agroforestry systems	**Atlantic**		**Continental**		**Mediterranean**		**EU3bR**	
Biomass carbon removal rates CO_2								
	2018	2030	2018	2030	2018	2030	2018	2030
Silvopastoral	5.13	61.63	16.25	195.06	43.56	296.66	64.95	779.28
Silvoarable	5.90	70.83	4.22	50.61	13.57	92.52	23.70	284.43
Total	11.04	132.46	20.47	245.67	57.14	389.18	88.66	1063.71

Silvoarable systems also demonstrate considerable carbon sequestration potential, though generally lower than that of silvopastoral systems due to lower tree density, younger trees, and relatively small areas.

3.3.3.2.2 Biomass carbon removal potentials by 2030

This analysis assumes that the 2018 agroforestry areas and their carbon removal rates will remain unchanged up until 2030. This was done by multiplying the 2018 rates by the number of years (2018-2030), providing insights regarding biomass carbon that could be potentially removed by 2030.

The total potential biomass carbon that could potentially be removed by 2030 across all systems and regions is estimated to be around 1.06 giga tonnes of CO_2, (Table 20). Considering that these areas were identified for the year 2018 and there are 12 years between 2018-2030 this means that around 50% of the potential sequestration has already been removed by these systems as of 2024.
When comparing the two systems, silvopastoral systems generally offer a higher carbon removal potential, particularly in the Mediterranean bioregion, highlighting the importance of region-specific strategies in maximising the climate benefits of agroforestry practices as well way forward for increasing of agroforestry areas in the other regions.

3.3.4 Potential soil organic carbon (SOC) stock in topsoils (0-30 cm) of silvopastoral and silvoarable minerals soils

To estimate SOC of the selected agroforestry areas, it is necessary to stratify the area of these systems by 2019 IPCC climate zones and soil types (Carré et al., 2010; EU, 2010; Hiederer et al., 2010; Rodel Lasco et al., 2006). The climate and soil maps were combined to create a new distinct climate-soil map and then intersected with the maps of agroforestry areas where the later map was the base in which the standard soil organic carbon values of the agroforestry areas were obtained (EU, 2010; Rodel Lasco et al., 2006).

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3.3.4.1 IPCC climate zones in the study area

Table 21 presents an analysis of the distribution of the 2019 IPCC climate zones across the Atlantic, Continental, and Mediterranean bioregions. The data shows the areas in thousand hectares (Kha) and their respective percentages for each climate zone, (Figure 16 a). The total distribution across the EU3bR reveals that the cool temperate moist region is the most extensive, covering 38.03% of the total area, followed by warm temperate dry, which represents 31.35% of the total area. This is followed by warm temperate moist zones (18.41%). While the cool temperate dry zone covers a smaller proportion at 34,012.01 equivalent to 11.69%. Tropical dry regions cover the least (0.45%) while areas classified as “None" (no class), cover an area of 166.75 Kha (0.06%).

Table 21. 2019 IPCC climate zones and their corresponding areas

Climate zones	Atlantic		Continental		Mediterranean		EU3bR	
	Area in kha and their percentage							
	Area	%	Area	%	Area	%	Area	%
Cool temperate dry	1422.19	1.91	30397.42	24	2192.4	2.45	34012.01	11.69
Cool temperate moist	41131.3	55.16	64732.77	51.11	4763.12	5.31	110627.19	38.03
Warm temperate dry	6525.61	8.75	16158.3	12.76	68487.93	76.4	91171.84	31.35
Warm temperate moist	25421.19	34.09	15344.7	12.12	12795.66	14.27	53561.55	18.41
Tropical dry				-	1322.13	1.47	1322.13	0.45
Non	68.17	0.09	16.78	0.01	81.81	0.09	166.76	0.06
Total	74568.46	100	126649.97	100	89643.06	100	290861.48	100.00

In the Atlantic bioregion, the cool temperate moist zone is predominant, covering 55.16%, followed by warm temperate moist (34.09%) and warm temperate dry (8.75%). In the Continental bioregion, the cool temperate moist zone extents the largest area with (51.11%), and the cool temperate dry and warm temperate dry zones also contribute significantly with (24.00%) and (12.76%) respectively. The Mediterranean bioregion is mainly characterised by the warm temperate dry zones, covering 68,487.93 Kha (76.40%), and includes warm temperate moist (14.27%) and cool temperate moist zones (4,763.12 Kha, 5.31%).
Comparing the figures of the three bioregions indicates that the Atlantic region is largely dominated by the cool temperate moist zones, opposing the Mediterranean region where the warm temperate dry zone is prevalent. The Continental region shows a balance with substantial areas of both cool temperate moist and warm temperate dry zones.

3.3.4.2 Soil classes in the study area

This analysis explores the distribution of various soil classes across the Atlantic, Continental, and Mediterranean bioregions. The data, derived from soil map, provides insights into the spatial extent and percentage coverage of different soil types within these regions (Figure 16 b). Table 22 reveals the total distribution of soil classes across the EU3bR area. High activity clay soils dominate the landscape, covering an area of 238,240.48 Kha, which represents 81.86% of the total study area. Other significant soil classes

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include Spodic soils (9.36%), Organic soils (2.61%), and wetland soils (2.99%). Low activity clay soils, sandy soils, volcanic soils, and areas classified as "none" or "other" make up smaller proportions of the total area.

Table 22. areas of EU3bR soil classes and their distribution

Soil class	Atlantic		Continental		Mediterranean		EU3bR	
	area in kha and their percentage in different bioregions							
	Area	%	Area	%	Area	%	Area	%
High activity clay soils	49625.03	66.38	101854.33	80.35	86761.12	96.94	238240.48	81.86
Low activity clay soils	47.39	0.06	879.72	0.69	676.48	0.76	1603.59	0.55
Organic	5289.12	7.08	2304.47	1.82	20.15	0.02	7613.74	2.61
Sandy soils	723.94	0.97	2425.37	1.91	500.30	0.56	3649.60	1.25
Spodic soils	11899.18	15.92	14420.53	11.38	935.60	1.05	27255.32	9.36
Volcanic soils	-	0.00	514.55	0.41	133.33	0.15	647.88	0.22
Wetland soils	5588.18	7.48	3133.82	2.47	-	-	8722.00	2.99
Other areas	1509.67	2.02	1208.37	0.95	389.29	0.43	3107.32	1.06
None	71.08	0.10	16.78	0.01	81.81	0.09	169.66	0.05
Total	74753.57	100.00	126757.93	100.00	89498.08	100.00	291009.59	100

In the Atlantic bioregion, high activity clay soils covered (66.38%), followed by Spodic soils (15.92%), and organic soils (7.08%). The Continental bioregion is similarly dominated by high activity clay soils, which span 101,854.33 Kha (80.35%). Spodic soils and sandy soils also contribute significant areas of (11.38%) and (1.91%) respectively. In the Mediterranean bioregion, high activity clay soils cover a vast majority, (96.94%), with minimal contributions from other soil classes such as Spodic soils (1.05%) and sandy soils (0.56%).

The analysis highlights the prevalence of high activity clay soils across all regions, particularly in the Mediterranean where they account for almost the entire soil coverage. The Continental region shows a significant presence of Spodic soils alongside high activity clay soils, whereas the Atlantic region has notable areas of Spodic and organic soils.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

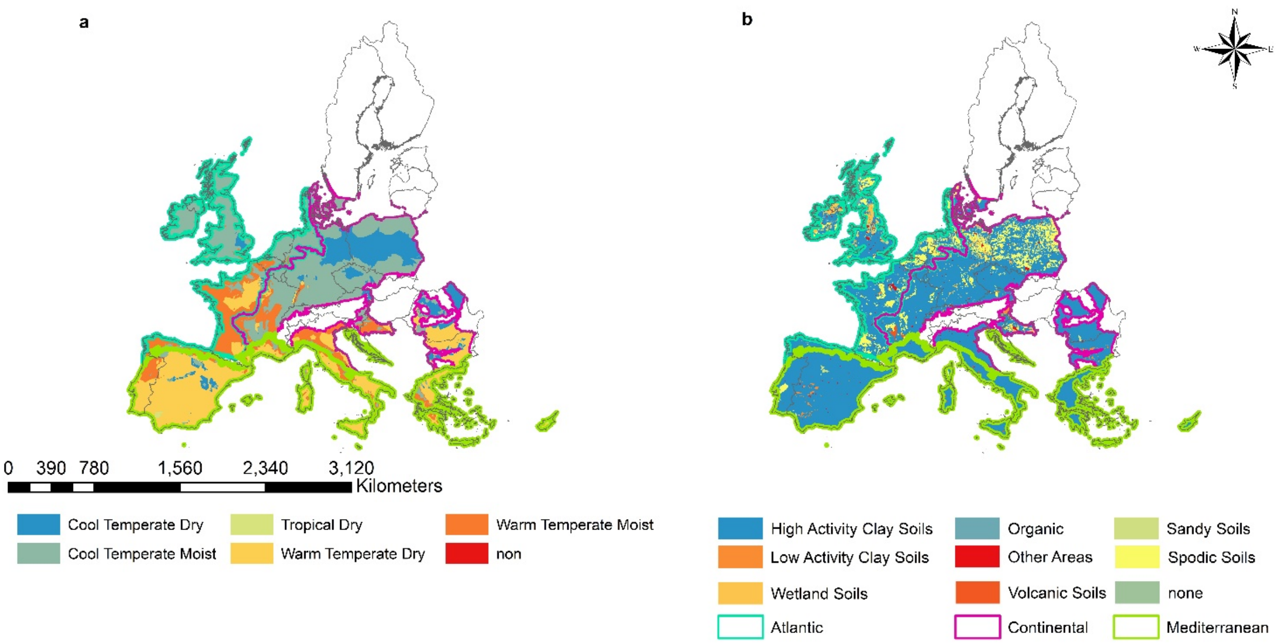

Figure 16. a) 2019 IPCC climate zones and b) soil classes maps(Carré et al., 2010)

3.3.4.3 Identified climate - Soil zones

This analysis is based on the previous two analyses and utilises the 2019 IPCC climate zones map combined with a soil map to identify intersecting areas within different biogeographical regions. The goal is to calculate the standard soil organic carbon (SOC) for these regions, offering insights into the spatial distribution and variability of SOC across the Atlantic, Continental, and Mediterranean bioregions.

Table 23 shows the total distribution of climate-soil classes across the study area and highlights the diversity and extent of different climate soil combinations. The warm temperate dry region with high activity clay soils class spans 86,378.90 Kha (29.63% of the total area). This is followed by the cool temperate moist - high activity clay soils class, which cover 27.06%. Other significant classes include cool temperate moist - Spodic soils (5.30%) and warm temperate moist - high activity clay soils (47,665.28 Kha, 16.35%). These major classes collectively dominate the landscape, reflecting the prevalent climatic regions and soil types across the study region (Figure 17).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

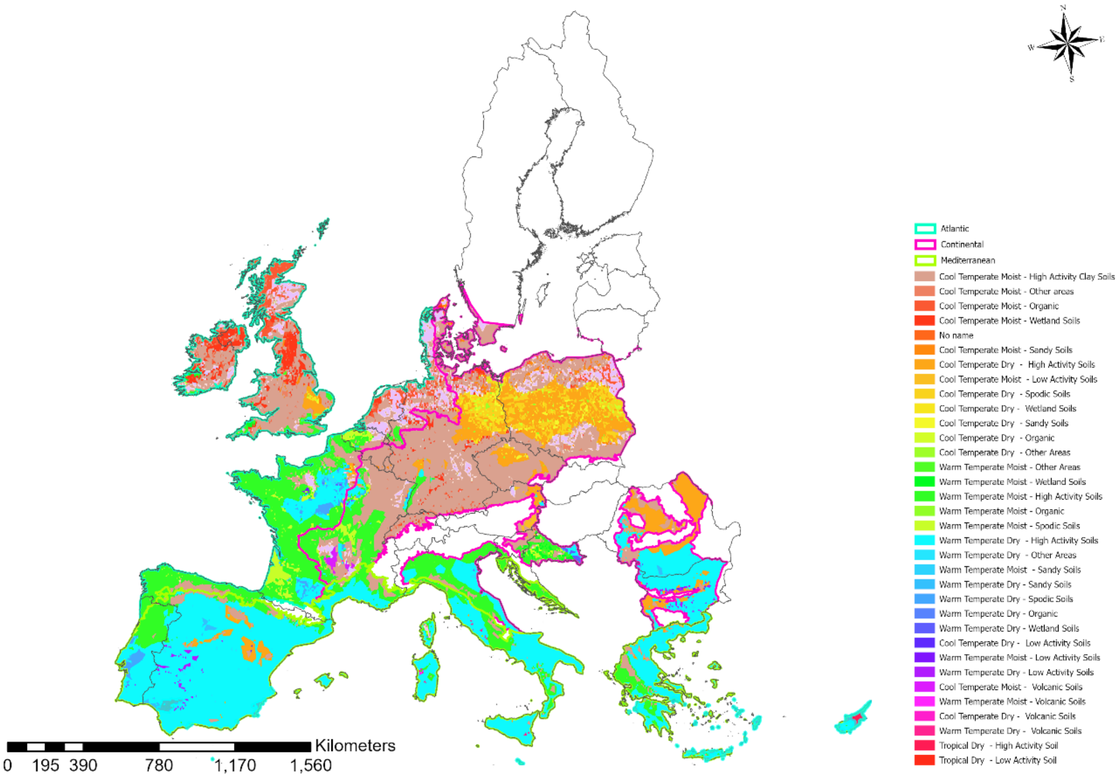

Figure 17. Identified Climate - soil regions in the study area

In the Atlantic bioregion, the dominant classes include cool temperate moist - high activity clay soils (29.12%) and warm temperate moist, high activity clay soils (28.87%). In the Continental bioregion, the largest areas are covered by cool temperate moist - high activity clay soils (41.31%) and warm temperate dry - high activity clay soils (11.92%). The Mediterranean bioregion is predominantly characterised by warm temperate dry - high activity clay soils (73.75%) followed by warm temperate moist - high activity clay soils, which accounts for 14.13%.

It is evident that high activity clay soils, both in moist and dry climates, constitute the largest areas. The cool temperate moist - high activity clay soils class is particularly extensive in the Atlantic and Continental bioregions, while the Mediterranean bioregion is largely dominated by warm temperate dry - high activity clay soils.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

Table 23. The areas of climate - soil classes and their distributions

Climate - soils classes	Atlantic		Continental		Mediterranean		EU3bR	
	Classes area in Kha and their percentage in different bioregions							
	Area	%	Area	%	Area	%	Area	%
Cool temperate moist - volcanic soils	-	-	491.79	0.39	-	-	491.79	0.17
Cool temperate moist - low activity soils	-	-	474.63	0.37	-	-	474.63	0.16
Cool temperate moist - spodic soils	8071.27	10.78	7280.20	5.74	96.17	0.11	15447.64	5.30
Cool temperate moist - high activity clay soils	21814.92	29.12	52407.09	41.31	4678.94	5.21	78900.95	27.06
Cool temperate moist - other areas	901.00	1.20	609.78	0.48	3.61	-	1514.39	0.52
Cool temperate moist – organic	5146.03	6.87	1211.61	0.96	5.12	0.01	6362.75	2.18
Cool temperate moist - wetland soils	5094.06	6.80	1327.93	1.05	-	-	6421.98	2.20
Cool temperate moist - sandy soils	319.54	0.43	1109.61	0.87	-	-	1429.16	0.49
Cool temperate dry - volcanic soils	-	-	12.01	0.01	-	-	12.01	0.00
Cool temperate dry - low activity clay soils	-	-	123.63	0.10	11.15	0.01	134.78	0.05
Cool temperate dry - high activity clay soils	1123.98	1.50	20804.40	16.40	2178.82	2.43	24107.20	8.27
Cool temperate dry - spodic soils	37.27	0.05	5882.63	4.64	-	-	5919.90	2.03
Cool temperate dry - wetland soils	108.24	0.14	1114.51	0.88	-	-	1222.74	0.42
Cool temperate dry - sandy soils	78.77	0.11	1187.02	0.94	-	-	1265.79	0.43
Cool temperate dry - organic	34.96	0.05	1078.53	0.85	-	-	1113.49	0.38
Cool temperate dry - other areas	44.91	0.06	207.25	0.16	4.12	-	256.28	0.09
Warm temperate moist - other areas	302.76	0.40	231.35	0.18	36.33	0.04	570.45	0.20
Warm TEMPERATE MOIST - WETLAND SOILS	370.03	0.49	542.48	0.43			912.51	0.31
Warm temperate moist - high activity clay soils	21622.02	28.87	13352.54	10.53	12690.72	14.13	47665.28	16.35
Warm temperate moist – organic	132.27	0.18	8.76	0.01	12.38	0.01	153.41	0.05
Warm temperate moist - spodic soils	2845.06	3.80	1176.54	0.93	72.13	0.08	4093.72	1.40
Warm temperate moist - sandy soils	226.06	0.30	21.01	0.02	3.64	0.00	250.72	0.09
Warm temperate moist - low activity clay soils	49.48	0.07	-	-	-	-	49.48	0.02
Warm temperate moist - volcanic soils	-	-	11.99	0.01	31.67	0.04	43.65	0.01
Warm temperate dry - high activity clay soils	5025.37	6.71	15125.83	11.92	66227.70	73.75	86378.90	29.63
Warm temperate dry - other areas	299.23	0.40	179.49	0.14	356.44	0.40	835.16	0.29
Warm temperate dry - sandy soils	136.39	0.18	135.85	0.11	500.45	0.56	772.70	0.27
Warm temperate dry - spodic soils	1011.88	1.35	151.81	0.12	783.25	0.87	1946.94	0.67
Warm temperate dry – organic	5.48	0.01	28.65	0.02	4.49	0.01	38.62	0.01
Warm temperate dry - wetland soils	29.64	0.04	213.84	0.17	-	-	243.47	0.08
Warm temperate dry - low activity clay soils	-	-	333.13	0.26	584.70	0.65	917.83	0.31
Warm temperate dry - volcanic soils	-	-	-	-	102.31	0.11	102.31	0.04
Tropical DRY - HIGH ACTIVITY SOIL	-	-	-	-	1237.34	1.38	1237.34	0.42
Tropical DRY - LOW ACTIVITY SOIL	-	-	-	-	98.70	0.11	98.70	0.03
None	74.69	0.10	17.19	0.01	83.78	0.09	175.67	0.06
Total	74905.32	100.00	126853.08	100.00	89803.97	100.00	291562.37	100.00

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

3.3.4.4 Distribution of the selected agroforestry systems based on climate-soil regions

To determine the corresponding standard soil organic carbon value of each classified area, the selected silvopastoral and silvoarable agroforestry maps were intersected with the climate-soil regions map generated in the previous step using ArcGIS.

3.3.4.4.1 Silvopastoral areas based on climate-soil regions

The total silvopastoral area across the EU3bR sums to 6.2 M ha, which is distributed among various climate-soil regions (Table 24). The largest proportion of this area is found in warm temperate dry regions with high activity clay soils, which accounts for 3.9 M ha or 63.79% of the total silvopastoral area in the EU3bR. Around 16.56% or 1035.93 Kha of silvopastoral areas falls within cool temperate moist regions with high activity clay soils and 6.16% in warm temperate moist regions with high activity clay soils.

In the Atlantic bioregion, the total silvopastoral area is 466.43 Kha. The largest portion of this area is associated with the cool temperate moist - high activity clay soils class, which accounts for 138.02 Kha equivalent to 29.59% of the total silvopastoral areas in Atlantic bioregion. This is followed by warm temperate moist - high activity clay soils (31.24%) and cool temperate moist - Spodic soils (13.63%). These figures indicate that in the Atlantic region, Silvopastoral areas are predominantly found in moist climates with high activity clay soils.
The Continental bioregion has a total silvopastoral area of 1.3 M ha. The most extensive area is found within the cool temperate moist with high activity clay soils, covering 788.41 Kha (57.14% of the Continental total). This is followed by areas in cool temperate moist regions with Spodic soils (4.98%) and in cool temperate moist - sandy soils (6.62%). The data highlights the prominence of moist climate regions associated with high activity clay soils in the Continental bioregion, which a significant portion of the silvopastoral areas fall within.

In the Mediterranean bioregion, the total Silvopastoral area is 4.4 M ha, with a significant majority of this area classified under warm temperate dry - high activity clay soils, accounting for 3.7 M ha or 87.95% of the Mediterranean total. The next largest areas exist within cool temperate moist with high activity clay soils (2.48%) followed by areas within warm temperate dry regions with Spodic soils (1.05%). These figures show that the Mediterranean region's silvopastoral areas are largely concentrated in dry, warm temperate climates with high activity clay soils.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

Table 24. the distribution of silvopastoral areas based on climate-soil regions

Climate-soil regions	Atlantic		Continental		Mediterranean		EU3bR	
	Classes area in Kha and their percentage in different bioregions							
	area	%	area	%	area	%	area	%
Cool temperate dry - high activity clay soils	1.06	0.23	194.73	14.11	62.81	1.42	258.60	4.13
Cool temperate dry - low activity clay soils	0.00	0.00	5.11	0.37	0.01	0.00	5.12	0.08
Cool temperate dry - organic	0.42	0.09	6.12	0.44	0.00	0.00	6.54	0.10
Cool temperate dry - other areas	0.07	0.02	0.78	0.06	0.04	0.00	0.89	0.01
Cool temperate dry - sandy soils	0.28	0.06	7.45	0.54	0.00	0.00	7.73	0.12
Cool temperate dry - spodic soils	0.09	0.02	39.28	2.85	0.00	0.00	39.37	0.63
Cool temperate dry - volcanic soils	0.00	0.00	0.04	0.00	0.00	0.00	0.04	0.00
Cool temperate dry - wetland soils	0.12	0.03	7.55	0.55	0.00	0.00	7.66	0.12
Cool temperate moist - low activity clay soils	0.00	0.00	3.14	0.23	0.00	0.00	3.14	0.05
Cool temperate moist - volcanic soils	0.00	0.00	9.18	0.67	0.00	0.00	9.18	0.15
Cool temperate moist - high activity clay soils	138.02	29.59	788.41	57.14	109.50	2.48	1035.93	16.56
Cool temperate moist - organic	22.24	4.77	14.23	1.03	0.00	0.00	36.47	0.58
Cool temperate moist - other areas	4.48	0.96	6.31	0.46	0.00	0.00	10.80	0.17
Cool temperate moist - sandy soils	1.49	0.32	8.56	0.62	0.00	0.00	10.05	0.16
Cool temperate moist - spodic soils	63.60	13.63	68.65	4.98	1.60	0.04	133.85	2.14
Cool temperate moist - wetland soils	48.01	10.29	15.49	1.12	0.00	0.00	63.50	1.01
Warm temperate dry - high activity clay soils	16.50	3.54	95.40	6.91	3879.83	87.95	3991.72	63.79
Warm temperate dry - other areas	0.23	0.05	0.34	0.02	22.80	0.52	23.37	0.37
Warm temperate dry - volcanic soils	0.00	0.00	0.00	0.00	6.10	0.14	6.10	0.10
Warm temperate dry - low activity clay soils	0.00	0.00	7.49	0.54	109.19	2.48	116.69	1.86
Warm temperate dry - organic	0.02	0.00	0.19	0.01	0.00	0.00	0.21	0.00
Warm temperate dry - sandy soils	0.31	0.07	0.10	0.01	4.93	0.11	5.35	0.09
Warm temperate dry - spodic soils	5.78	1.24	0.37	0.03	46.41	1.05	52.57	0.84
Warm temperate dry - wetland soils	0.00	0.00	0.22	0.02	0.00	0.00	0.23	0.00
Warm temperate moist - sandy soils	0.83	0.18	0.08	0.01	0.00	0.00	0.91	0.01
Warm temperate moist - high activity clay soils	145.70	31.24	86.68	6.28	153.15	3.47	385.53	6.16
Warm temperate moist - low activity clay soils	0.07	0.02	0.00	0.00	0.00	0.00	0.07	0.00
Warm temperate moist - organic	0.59	0.13	0.05	0.00	0.04	0.00	0.68	0.01
Warm temperate moist - other areas	0.72	0.15	0.58	0.04	0.28	0.01	1.57	0.03
Warm temperate moist - spodic soils	11.38	2.44	9.53	0.69	0.36	0.01	21.26	0.34
Warm temperate moist - volcanic soils	0.00	0.00	0.18	0.01	2.30	0.05	2.48	0.04
Warm temperate moist - wetland soils	4.00	0.86	3.53	0.26	0.00	0.00	7.54	0.12
Tropical dry - high activity clay soil	0.00	0.00	0.00	0.00	10.15	0.23	10.15	0.16
Tropical dry - low activity clay soil	0.00	0.00	0.00	0.00	1.66	0.04	1.66	0.03
None	0.43	0.09	0.02	0.00	0.11	0.00	0.55	0.01
Total	466.43	100.00	1379.80	100.00	4411.29	100.00	6257.52	100.00

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3.3.4.4.2 Silvoarable areas based on climate-soil regions

The total silvoarable area across the EU3bR is 3.9 M ha, which is distributed among various climate-soil regions (Table 25). The largest portion of such land use is found in warm temperate dry - high activity clay soils, which account for 1962.49 Kha or 49.67% of total classified silvoarable areas. This is followed by areas in cool temperate moist regions with high activity clay soils (17.85%). Other significant areas were found within warm temperate moist regions with high activity clay soils (11.93%).

In the Atlantic bioregion, the total silvoarable area is 420.05 Kha. The most significant portion of this area is classified under Warm Temperate Moist regions with High Activity Clay Soils accounting for 135.77 Kha (32.34% of the Atlantic total). This is followed by areas with cool temperate moist regions with high activity clay soils (19.27%) and warm temperate dry - high activity clay soils (10.43%). These figures imply that in the Atlantic region, silvoarable areas are predominantly associated with high activity clay soils in both warm and cool temperate climate regions.

The Continental bioregion has a total Silvoarable area of 1473.68 Kha. The most extensive area is found in the cool temperate moist regions associated with high activity clay soils, covering 590.03 Kha (40.04% of the Continental total). This is followed by areas within cool temperate dry - high activity clay soils, warm temperate dry - high activity clay soils and warm temperate moist - high activity clay soils, representing 16.77, 14.36 and 10.64% respectively.

While in the Mediterranean bioregion, the total silvoarable area is 2057.13 Kha. The areas within warm temperate dry climate regions with high activity clay soils accounts for 1707.06 Kha (83.04% of the Mediterranean total). The next largest areas fall in warm temperate moist regions with high activity clay soils (8.72%). These figures show that the Mediterranean region's Silvoarable areas are largely concentrated in warm temperate climates, particularly those with high-activity clay soils.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

Table 25. the distribution of Silvoarable areas based on climate -soil regions

Climate-soil regions	Atlantic		Continental		Mediterranean		EU3bR	
	area in kha and their percentage in different bioregions							
	area	%	area	%	area	%	area	%
Cool temperate dry - high activity clay soils	5.05	1.20	247.13	16.77	20.83	1.01	273.01	6.91
Cool temperate dry - low activity clay soils	0.00	0.00	7.73	0.52	0.09	0.00	7.82	0.20
Cool temperate dry - organic	0.27	0.06	6.27	0.43	0.00	0.00	6.54	0.17
Cool temperate dry - other areas	0.23	0.05	0.64	0.04	0.00	0.00	0.86	0.02
Cool temperate dry - sandy soils	0.84	0.20	16.21	1.10	0.00	0.00	17.05	0.43
Cool temperate dry - spodic soils	0.16	0.04	61.90	4.20	0.00	0.00	62.06	1.57
Cool temperate dry - wetland soils	0.35	0.08	8.82	0.60	0.00	0.00	9.17	0.23
Cool temperate moist - low activity clay soils	0.00	0.00	6.72	0.46	0.00	0.00	6.72	0.17
Cool temperate moist - volcanic soils	0.00	0.00	0.33	0.02	0.00	0.00	0.33	0.01
Cool temperate moist - high activity clay soils	80.96	19.27	590.03	40.04	34.13	1.66	705.11	17.85
Cool temperate moist - organic	8.50	2.02	10.54	0.72	0.00	0.00	19.04	0.48
Cool temperate moist - other areas	1.49	0.36	3.88	0.26	0.03	0.00	5.40	0.14
Cool temperate moist - sandy soils	2.70	0.64	15.77	1.07	0.00	0.00	18.47	0.47
Cool temperate moist - spodic soils	64.79	15.42	89.28	6.06	0.02	0.00	154.09	3.90
Cool temperate moist - wetland soils	14.90	3.55	13.91	0.94	0.00	0.00	28.81	0.73
Warm temperate dry - high activity clay soils	43.80	10.43	211.63	14.36	1707.06	82.98	1962.49	49.67
Warm temperate dry - other areas	0.92	0.22	1.08	0.07	3.94	0.19	5.94	0.15
Warm temperate dry - volcanic soils	0.00	0.00	0.00	0.00	4.13	0.20	4.13	0.10
Warm temperate dry - low activity clay soils	0.00	0.00	13.92	0.94	34.26	1.67	48.17	1.22
Warm temperate dry - organic	0.02	0.00	0.16	0.01	0.00	0.00	0.17	0.00
Warm temperate dry - sandy soils	1.18	0.28	0.19	0.01	10.77	0.52	12.15	0.31
Warm temperate dry - spodic soils	20.09	4.78	0.88	0.06	6.26	0.30	27.23	0.69
Warm temperate dry - wetland soils	0.40	0.10	0.87	0.06	0.00	0.00	1.27	0.03
Warm temperate moist - sandy soils	0.81	0.19	0.06	0.00	0.00	0.00	0.87	0.02
Warm temperate moist - high activity clay soils	135.77	32.32	156.80	10.64	179.44	8.72	472.02	11.95
Warm temperate moist - low activity clay soils	0.14	0.03	0.00	0.00	0.00	0.00	0.14	0.00
Warm temperate moist - organic	0.46	0.11	0.03	0.00	0.12	0.01	0.62	0.02
Warm temperate moist - other areas	0.60	0.14	1.18	0.08	0.71	0.03	2.49	0.06
Warm temperate moist - spodic soils	34.29	8.16	4.57	0.31	0.61	0.03	39.48	1.00
Warm temperate moist - volcanic soils	0.00	0.00	0.00	0.00	0.43	0.02	0.43	0.01
Warm temperate moist - wetland soils	1.11	0.26	3.10	0.21	0.00	0.00	4.21	0.11
Tropical dry - high activity clay soil	0.00	0.00	0.00	0.00	43.54	2.12	43.54	1.10
Tropical dry - low activity clay soil	0.00	0.00	0.00	0.00	9.35	0.45	9.35	0.24
None	0.24	0.06	0.05	0.00	1.41	0.07	1.69	0.04
Total	420.05	100.00	1473.68	100.00	2057.13	100.00	3950.86	100.00

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

3.3.4.5 SOC stock based on soil classes

The intersected agroforestry areas with the climate-soil regions identified in the previous analysis were used to select their corresponding standard SOC values for mineral soils (topsoil 0-30 cm). Land use, management and input factors were also considered. Then these values were multiplied by the areas to obtain the potential soil organic carbon stock.

Table 26 shows the potential SOC stock of the classified silvopastoral and silvoarable systems, categorised by soil classes. The SOC is expressed in million tonnes of carbon (SOC Mt C), million tonnes of carbon dioxide (Mt CO_2), and as a percentage of the total SOC (%) for each soil class. This provides a breakdown of the carbon storage potential of different soil types under agroforestry systems, with a focus on silvopastoral and silvoarable practices.

Table 26. Potential SOC stock of silvopastoral and silvoarable areas based on Soil classes

Classes	Silvopastoral			Silvoarable			EU3bR		
	M t C	Mt CO_2	SOC %	M t C	Mt CO_2	SOC %	M t C	Mt CO_2	SOC %
High activity clay soils	338.87	1243.66	91.27	153.91	564.87	88.47	492.79	1808.53	90.38
Low activity clay soils	3.71	13.61	1.00	1.65	6.05	0.95	5.36	19.66	0.98
None	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Organic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other areas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sandy soils	1.21	4.46	0.33	1.65	6.05	0.95	2.86	10.51	0.53
Spodic soils	17.70	64.98	4.77	13.55	49.72	7.79	31.25	114.69	5.73
Volcanic soils	1.96	7.18	0.53	0.30	1.10	0.17	2.26	8.28	0.41
Wetland soils	7.81	28.67	2.10	2.92	10.71	1.68	10.73	39.38	1.97
Total	371.27	1362.55	100.00	173.98	638.50	100.00	545.25	2001.05	100.00

As of 2018, the total estimated SOC stock is around 2 Gigatonne (Gt) CO_2 across both silvopastoral and silvoarable areas. Out that, around 90.38% or 1.8 Gt CO_2 is held within high activity clay soils while around 5.73 and 1.97% in Spodic soils and wetland soils respectively. Low activity clay, sandy, volcanic, and other soil types hold smaller portions of the total estimated SOC stock.

High activity clay soils of silvopastoral areas contribute the largest SOC stock, accounting for 91.27% of the total (SOC silvopastoral). Spodic soils and wetland soils contribute smaller amounts, accounting for 4.77% and 2.10% respectively (Figure 18). High activity clay soils in the silvoarable systems also dominate, contributing 88.47% of the total (SOC silvoarable), corresponding to 564.87 Mt CO_2. Spodic soils contribute 7.79%, while wetland soils add 2.92 Mt C (1.68%). Other soil types, such as low activity clay and sandy soils, make up less than 1% of the total SOC in silvoarable systems (Figure 19).

This breakdown points out the significant potential for SOC stock in high activity clay soils under agroforestry practices, with notable but smaller contributions from other soil classes. Taking into account that these agroforestry areas represent less than 7% of total agricultural area, the estimation is in line with that found for EU+UK grassland and cropland holding around 9 Giga of CO_2 in 2018 (De Rosa et al., 2023).

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3.3.4.6 SOC stock based on biogeographical regions

In terms of bioregions, the total SOC stock across both systems is dominated by the Mediterranean region, which has around 49.87% of the total estimated SOC stock. The remainder, 37.76 and 12.37% are found within Continental and Atlantic regions respectively (Table 27).

Table 27. Potential SOC stock of silvopastoral and silvoarable systems based on biogeographical regions

Regions	Silvopastoral			Silvoarable			EU3bR		
	M t C	Mt CO_2	SOC %	M t C	Mt CO_2	SOC %	M t C	Mt CO_2	SOC %
Atlantic	43.98	161.42	11.85	23.48	86.18	13.50	67.46	247.59	12.37
Continental	124.10	455.43	33.42	81.79	300.18	47.01	205.89	755.62	37.76
Mediterranean	203.19	745.72	54.73	68.70	252.14	39.49	271.90	997.87	49.87
Total	371.27	1362.55	100.00	173.98	638.50	100.00	545.25	2001.05	100.00

3.3.4.7 SOC stock of silvopastoral and silvoarable systems based on countries

Silvopastoral and silvoarable areas in Spain hold the largest SOC stock, with a total of 649.40 Mt CO_2, representing around 32. 45% of the total estimated SOC stock. The vast majority of Spain's soil carbon stock is found in where silvopastoral systems are practiced, which represent 79% of its total SOC stock, while the soils of silvoarable systems contribute 135.86 Mt CO_2 or 21% (Table 28).

Germany also has a considerable SOC stock, with a total SOC stock of 223.46 Mt CO_2 or 11.17% of the total. The silvopastoral systems contribute 154.24 Mt CO_2, which is 69% of the total, while the silvoarable systems contribute 69.22 Mt CO_2. France is another major contributor, with a total of 198.19 Mt CO_2 or 9.9% of total and silvopastoral systems soils store 145.83 Mt CO_2, representing approximately 73.55% of its total, while silvoarable areas contribute 52.36 Mt CO_2.

Other significant contributors include Italy and Portugal, representing 9.09 and 6.70% of the total respectively. In Italy, silvopastoral systems dominate with 107.63 Mt CO_2, while silvoarable systems provide 73.31 Mt CO_2. In Portugal, silvopastoral systems account for 120.65 Mt CO_2, with silvoarable systems contributing 33.35 Mt CO_2. Other countries like the United Kingdom, Poland, and Netherlands also make notable contributions to the overall carbon stock in the selected regions, though their combined figures are relatively smaller compared to those of the larger countries (Spain, France, and Germany).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

Table 28. Potential soil organic carbon stock of silvopastoral and silvoarable systems based on countries.

Countries	Silvopastoral			Silvoarable			EU3bR		
	M t C	Mt CO2 eq	SOC %	M t C	Mt CO2 eq	SOC %	M t C	Mt CO2 eq	SOC %
Austria	2.27	8.34	0.61	1.72	6.31	0.99	3.99	14.65	0.73
Belgium	4.92	18.04	1.32	2.03	7.45	1.17	6.94	25.49	1.27
Bulgaria	5.97	21.90	1.61	6.00	22.03	3.45	11.97	43.93	2.20
Switzerland	3.83	14.05	1.03	2.07	7.61	1.19	5.90	21.66	1.08
Cyprus	0.14	0.51	0.04	0.48	1.74	0.27	0.62	2.26	0.11
Czech Republic	8.94	32.82	2.41	7.13	26.16	4.10	16.07	58.99	2.95
Germany	42.03	154.24	11.32	18.86	69.22	10.84	60.89	223.46	11.17
Denmark	1.87	6.86	0.50	4.73	17.34	2.72	6.60	24.20	1.21
Greece	10.40	38.18	2.80	10.61	38.94	6.10	21.01	77.12	3.85
Spain	139.93	513.53	37.69	37.02	135.86	21.28	176.95	649.40	32.45
France	39.73	145.83	10.70	14.27	52.36	8.20	54.00	198.19	9.90
Croatia	3.11	11.40	0.84	1.95	7.17	1.12	5.06	18.57	0.93
Hungary	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Republic of Ireland	8.59	31.54	2.31	1.03	3.80	0.59	9.63	35.33	1.77
Italy	19.98	73.31	5.38	29.33	107.63	16.86	49.30	180.94	9.04
Lithuania		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Luxembourg	0.59	2.15	0.16	0.47	1.73	0.27	1.06	3.89	0.19
Malta	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Netherlands	1.51	5.53	0.41	0.58	2.13	0.33	2.09	7.66	0.38
Poland	11.92	43.73	3.21	15.78	57.90	9.07	27.69	101.63	5.08
Portugal	32.71	120.05	8.81	3.85	14.12	2.21	36.56	134.16	6.70
Romania	20.55	75.43	5.54	9.46	34.73	5.44	30.02	110.16	5.50
Sweden	1.12	4.10	0.30	2.63	9.64	1.51	3.74	13.74	0.69
Slovenia	0.63	2.32	0.17	0.29	1.08	0.17	0.93	3.40	0.17
Slovakia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
United Kingdom	10.54	38.68	2.84	3.68	13.52	2.12	14.22	52.20	2.61
Total	371.27	1362.55	100.00	173.98	638.50	100.00	545.25	2001.05	100.00

This analysis highlights Spain's significant role in the carbon sequestration potential of agroforestry systems in the selected region. Germany's strong position in SOC Stock reflects the importance of its silvopastoral systems, which dominate its total carbon stock.

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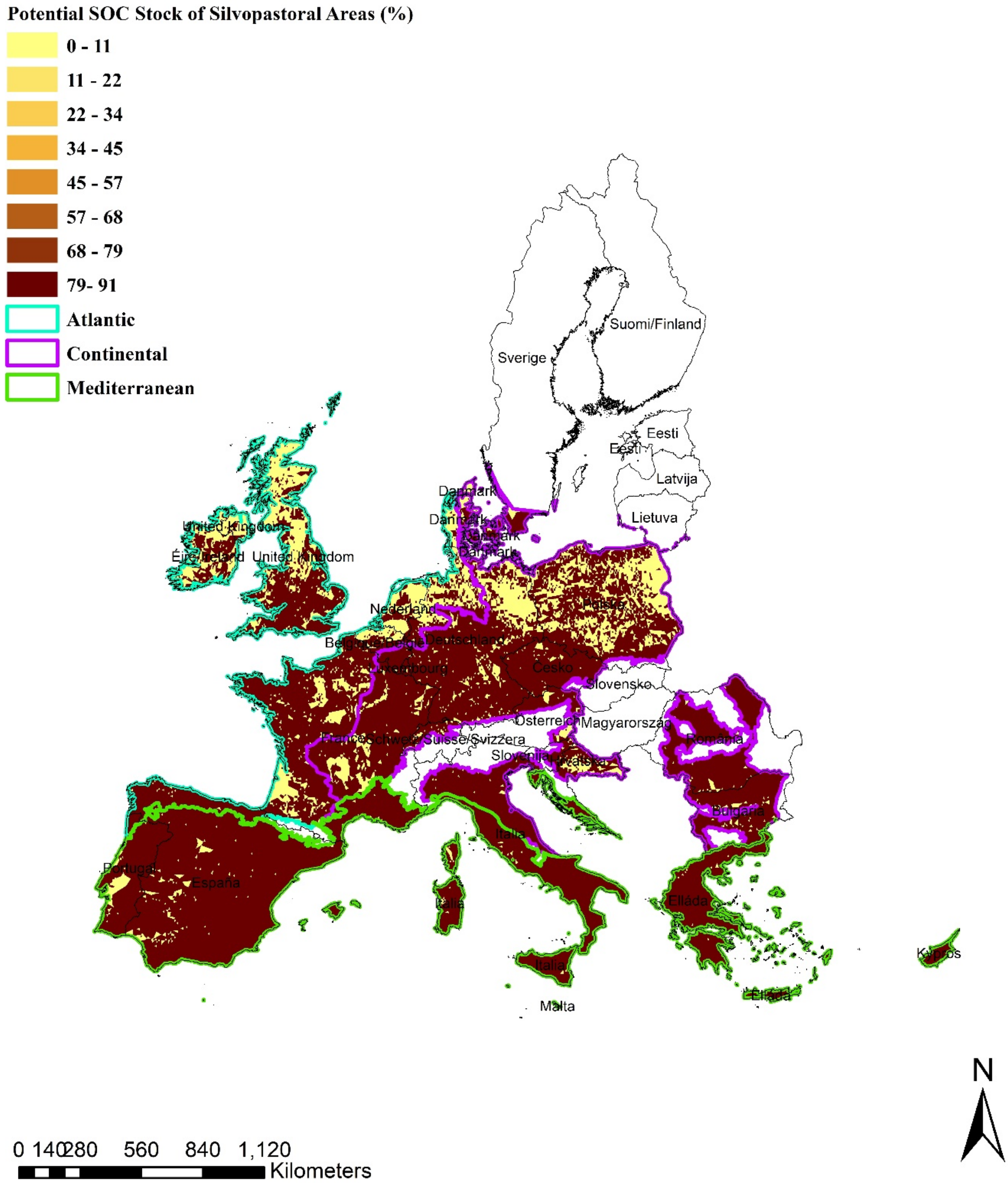

Figure 18. Potential SOC stock of silvopastoral areas (%)

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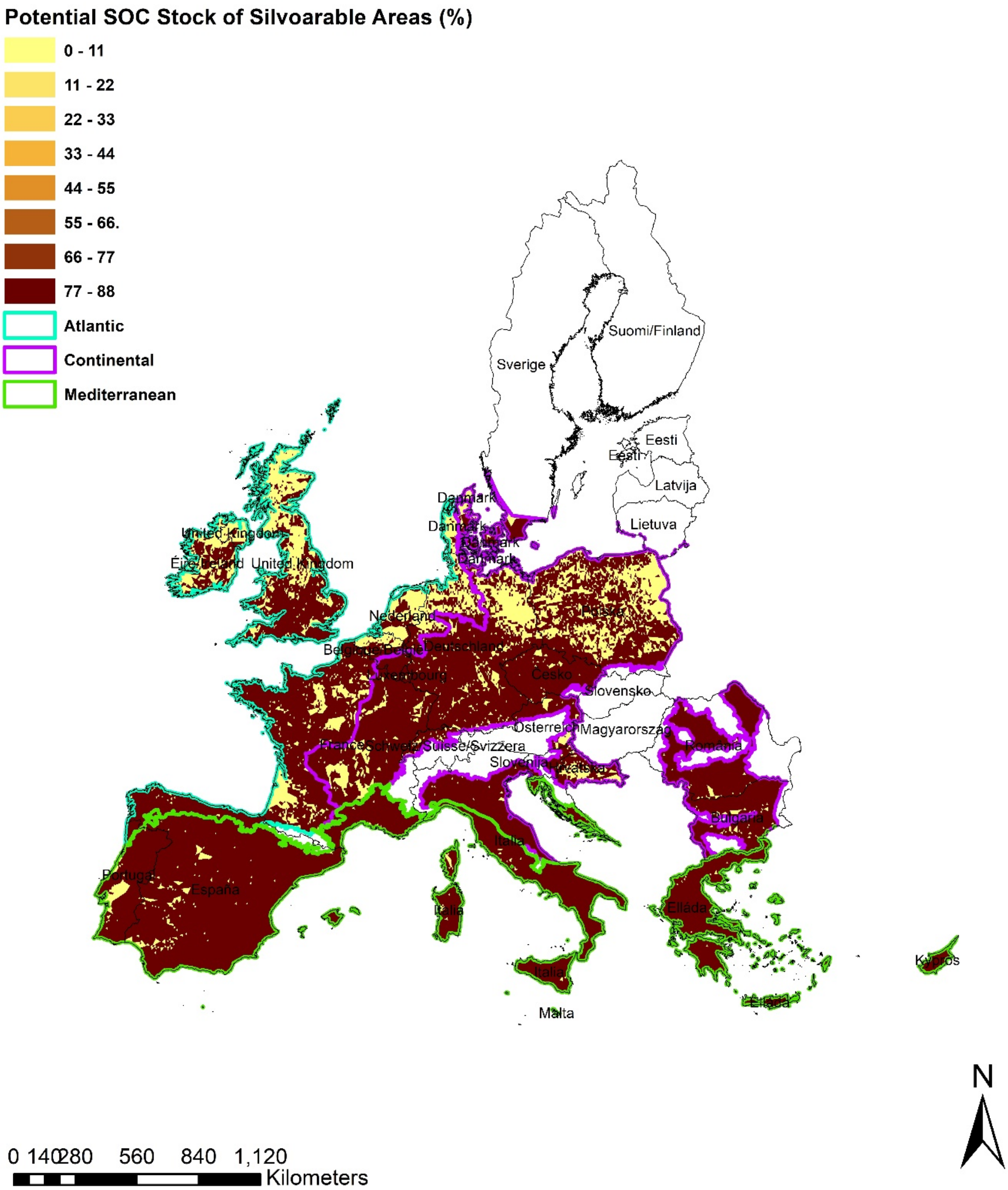

Figure 19. Potential SOC stock of Silvoarable areas

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

3.3.5 Potential emissions from silvopastoral and silvoarable agroforestry systems

To estimate the potential GHG emissions from agroforestry systems, related information and activity data regarding the relevant management activities were collected from the UK and Spanish sites. The relevant emission factors for management activities such as fertilisation and grazing were used to calculate the emissions per unit area of these systems.

3.3.5.1 Management activities within silvopastoral and silvoarable agroforestry systems

A few on-farm management activities and process within both silvopastoral and silvoarable systems were identified as activities with potential to contributing GHG (Table 29).

The major management activities and process contributing to GHG emissions in these systems include thinning, pruning, grazing, enteric fermentation, fertilisation, and harvesting. Of these, grazing and enteric fermentation are significant contributors, especially in silvopastoral systems, where animal-related activities play a major role in emissions.

Table 29. Default values of IPCC emission factors relevant to study sites (t CO_2 eq ha^{-1} $year^{-1}$)

Management activities	1st site		2nd site	Silvopastoral	Silvoarable
	Silvopastoral	Silvoarable	Silvopastoral	Mean	Mean
Thinning*	0.14	-	-	0.14	
Pruning*	0.18	-	-	0.18	
Grazing	4.40	-	2.9	3.67	
Enteric fermentation[1]	2.01	-	5.7×10^{-5}	1.0	
Fertilisation	0.74			0.74	
Harvesting	-	4.7	-		4.7
Total				5.73	4.7

*Estimation based on the available data from Loughgall

For silvopastoral systems, grazing stands out as a prominent source of emissions due to the facts that all grazed biomass by animals will be respired, while silvoarable systems contribute notably through harvesting activities. Additionally, thinning and pruning are relatively moderate contributors to emissions in the silvopastoral system, highlighting the role of forest management practices in carbon outputs. The overall total emissions in silvopastoral systems tend to be higher due to animal-related processes, while silvoarable systems demonstrate lower overall emissions driven mainly by harvesting and management interventions.

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3.3.5.2 Total potential emissions from silvopastoral and silvoarable agroforestry systems

Table 30 shows GHG potential emission from silvopastoral and silvoarable agroforestry areas across EU3bR area. In total, silvopastoral systems account for most emissions, representing approximately 65.96 % of the total emissions across the regions, while silvoarable systems contribute the remaining 34.13%**.** This distribution highlights the greater extent of silvopastoral practices in terms of both area and associated emissions (Figure 20).

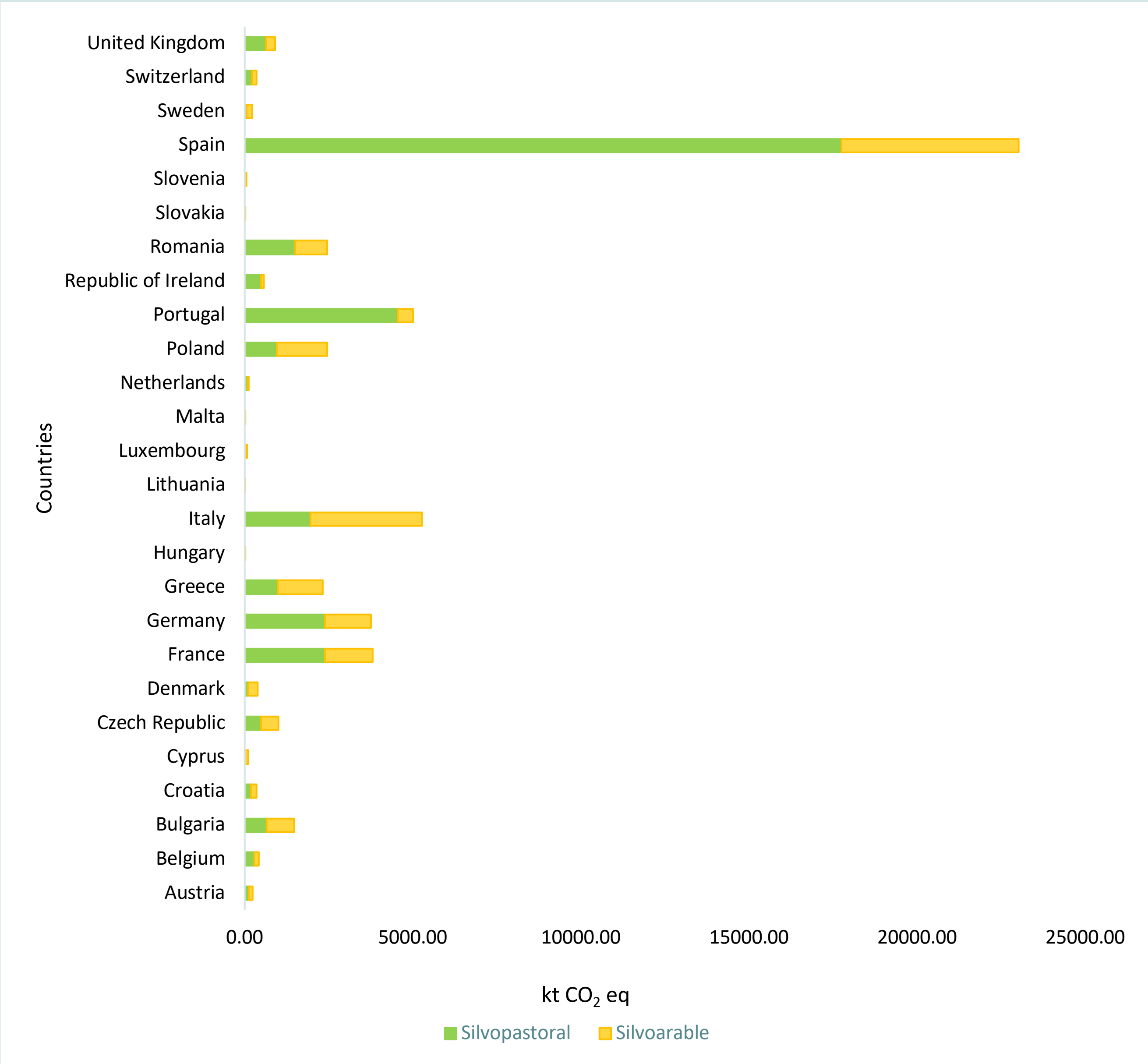

Figure 20. Emissions of silvopastoral and silvoarable areas in 2018

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Table 30. Total GHG emissions of silvopastoral and silvoarable areas

Country	Silvopastoral		Silvoarable	
	Area kha	Emissions Kt CO_2 eq	Area kha	Emissions Kt CO_2 eq
Austria	21.58	123.63	25.50	119.83
Belgium	48.92	280.33	30.84	144.95
Bulgaria	113.85	652.38	175.20	823.45
Croatia	33.48	191.84	33.59	157.89
Cyprus	3.26	18.65	17.26	81.14
Czech Republic	86.04	493.02	106.92	502.53
Denmark	16.70	95.68	62.67	294.55
France	416.42	2386.06	303.36	1425.79
Germany	417.35	2391.42	289.93	1362.67
Greece	171.62	983.39	284.90	1339.01
Hungary	0.01	0.07	0.04	0.18
Italy	341.98	1959.55	706.24	3319.34
Lithuania	0.00	0.00	0.00	0.00
Luxembourg	5.53	31.70	6.77	31.80
Malta	0.03	0.15	0.17	0.81
Netherlands	14.59	83.60	8.40	39.48
Poland	165.09	945.98	321.61	1511.58
Portugal	793.96	4549.38	97.79	459.63
Republic of Ireland	85.13	487.78	16.67	78.33
Romania	263.40	1509.28	199.88	939.42
Slovakia	0.01	0.08	0.01	0.06
Slovenia	5.91	33.86	4.32	20.32
Spain	3096.69	17744.01	1122.69	5276.63
Sweden	10.16	58.24	35.49	166.82
Switzerland	36.91	211.47	30.81	144.81
United Kingdom	110.56	633.50	56.68	266.40
Total	6259.17	35865.06	3937.75	18507.42

Countries like Spain, France, and Germany dominate both the land area and the emissions from silvopastoral systems. Spain, for instance, contributes a significant portion of the total emissions from silvopastoral systems due to its extensive adoption of these practices, followed by France and Germany. In these nations, silvopastoral systems have been implemented on vast tracts of land, resulting in their outsized share of the total emissions.

By comparison, smaller countries such as Malta, Luxembourg, and Slovenia have minimal contributions, reflecting their limited adoption of silvopastoral practices.
For silvoarable systems, Spain, Italy**,** and Poland emerge as the leading emitters, together contributing a considerable proportion of the emissions from this type of systems. Italy is notable for having a substantial share of silvoarable emissions due to its silvoarable areas. The table suggests a general trend where larger countries with more agricultural land tend to exhibit higher emissions from agroforestry systems, particularly from the silvopastoral category. However, the differences in emission levels across countries may also reflect variations in agroforestry management practices, land productivity, and system efficiency.

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3.3.5.3 Potential net emissions from silvopastoral and silvoarable agroforestry systems

The overall result indicates a significant net removal of greenhouse gases, with -34.1 M t CO_2 eq. Most of the removals, -29,07 kt CO2 eq, are attributed to silvopastoral systems**,** which play a dominant role in carbon sequestration, accounting for around 85% of the total removals (Table 31). The remaining portion of the carbon removal, about -5.07 M t CO_2 eq or 15%**,** is contributed by silvoarable areas. Despite contributing less to overall removals, silvoarable systems in countries like Spain, Romania and Portugal and still show notable carbon sequestration (Figure 21).

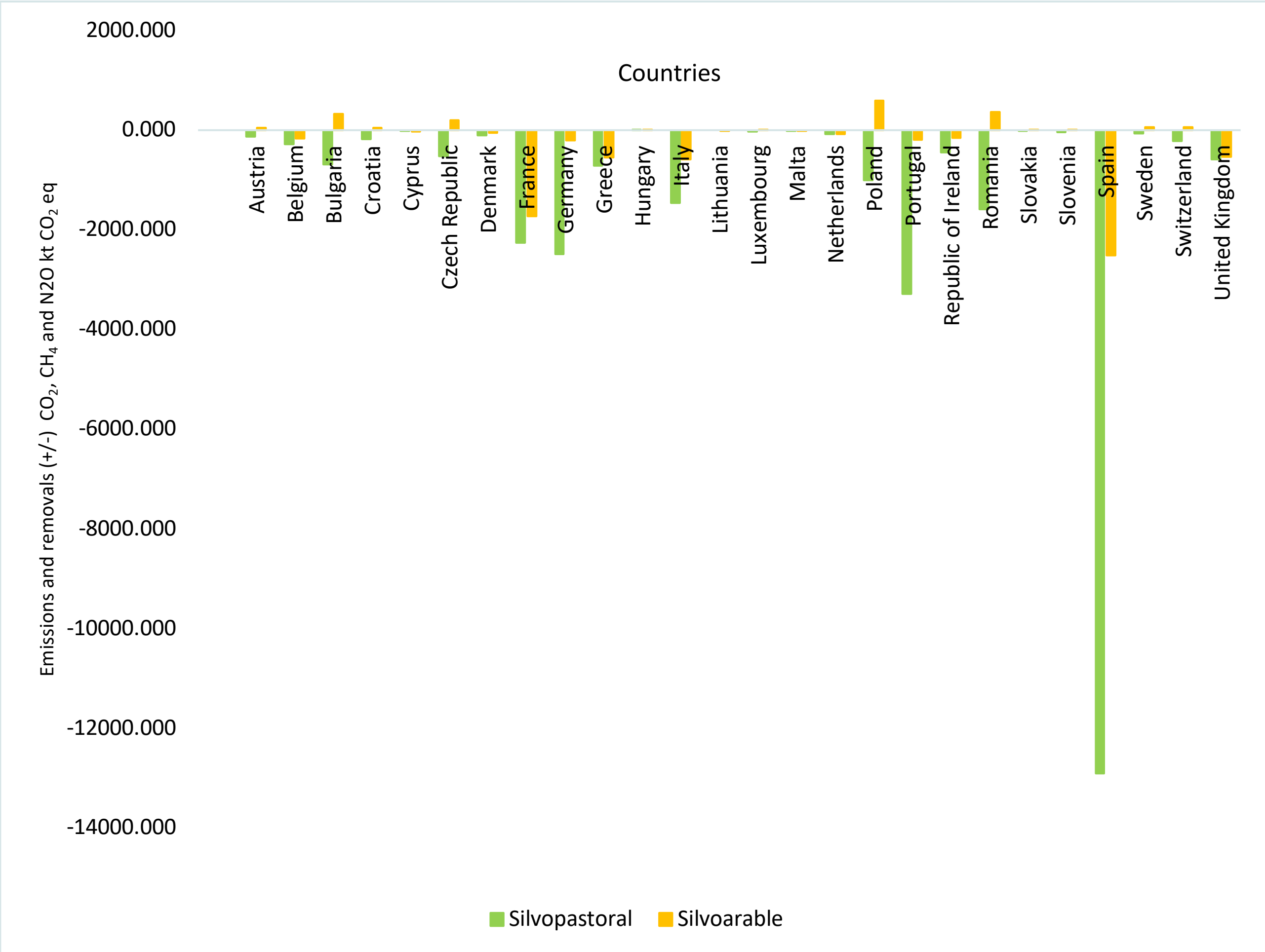

Figure 21. Emissions and removals (+/-) of silvopastoral and silvoarable systems kt CO_2 eq in 2018

Moreover, Spain, Portugal, Germany, and France are the largest contributors to net removals, with their silvopastoral systems playing a significant role in achieving these reductions. However, in some cases, like Belgium, Netherlands and United Kingdom, the silvoarable systems show positive net emissions, slightly offsetting the removals from silvopastoral systems. Overall, the data highlights the critical role of silvopastoral systems in achieving substantial greenhouse gas reductions and the potential for further enhancement in silvoarable systems to improve their carbon sequestration capacity (Figure 22).

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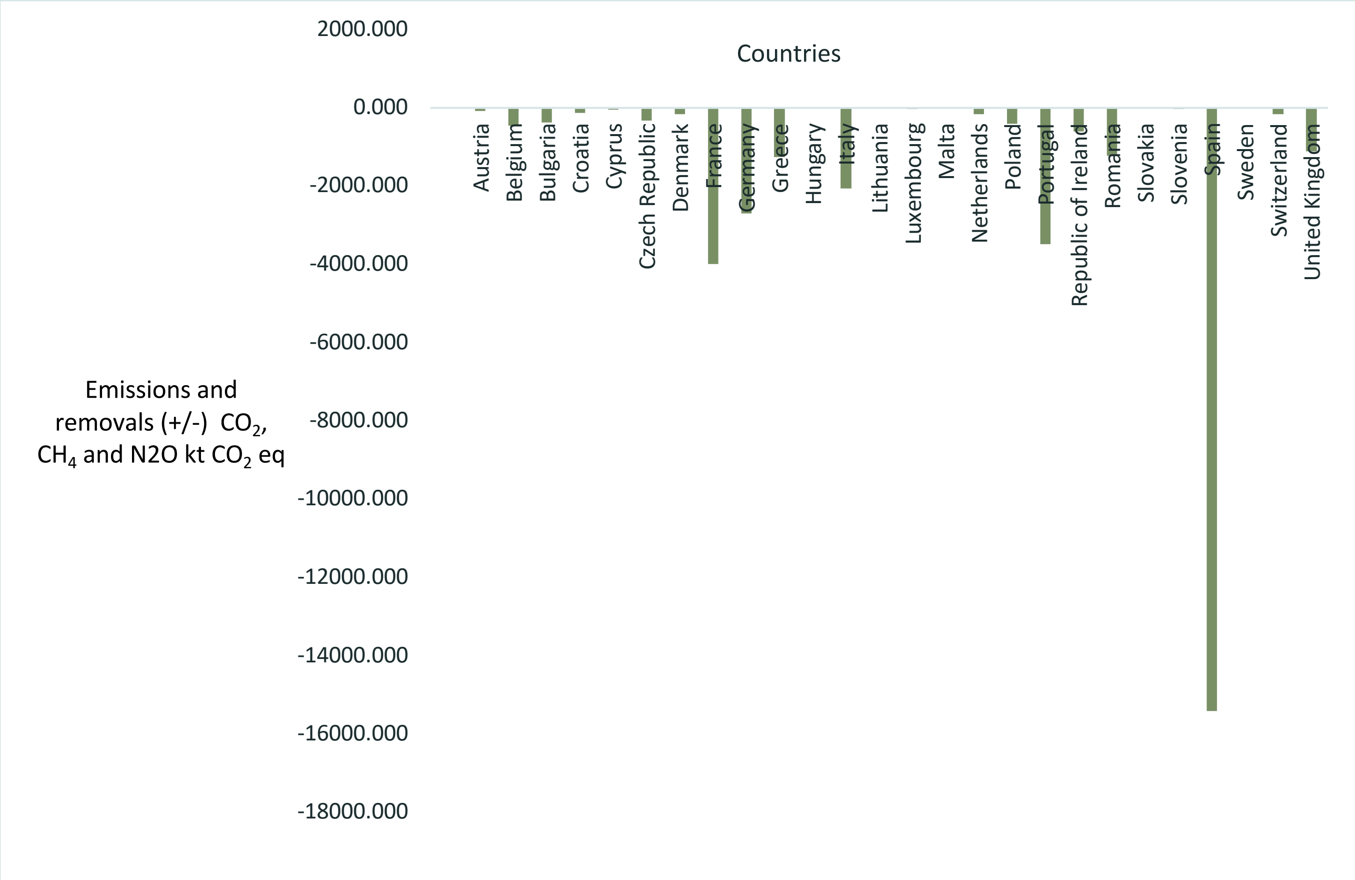

Figure 22. Total net emissions and removals (+/-) CO2, CH4 and N2O kt CO_2 eq both silvopastoral and silvoarable systems.

Furthermore, In the silvopastoral areas, several countries demonstrated significant carbon removal contributions. Spain leads, accounting for the largest share of carbon removal, followed by Portugal, Germany, and France, all of which have substantial percentages. However, much smaller contributions are noted for countries like Luxembourg, Slovenia, and Cyprus, where their percentages are minimal. Some countries, such as Lithuania and Slovakia, register zero removals, highlighting their lack of contribution to this agroforestry category.

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Table 31. Potential net emissions (+) of agroforestry areas in kilo tonne (kt) CO_2 eq, 2018

Country	Silvopastoral		Silvoarable		Total net emissions	
	Net emissions kt CO_2 eq	%	Net emissions kt CO_2 eq	%	kt CO_2 eq	%
Austria	-130.30	0.45	46.85	-0.92	-83.45	0.24
Belgium	-282.98	0.97	-164.61	3.24	-447.59	1.31
Bulgaria	-687.59	2.36	321.86	-6.34	-365.73	1.07
Croatia	-177.84	0.61	45.42	-0.89	-132.42	0.39
Cyprus	-13.49	0.05	-32.91	0.65	-46.40	0.14
Czech Republic	-520.59	1.79	196.46	-3.87	-324.13	0.95
Denmark	-99.98	0.34	-56.63	1.12	-156.61	0.46
France	-2260.53	7.78	-1722.50	33.92	-3983.03	11.66
Germany	-2487.73	8.56	-202.17	3.98	-2689.90	7.88
Greece	-709.48	2.44	-543.01	10.69	-1252.49	3.67
Hungary	0.03	0.00	0.07	0.00	0.10	0.00
Italy	-1464.45	5.04	-590.84	11.64	-2055.29	6.02
Lithuania	0.00	0.00	0.00	0.00	0.00	0.00
Luxembourg	-33.50	0.12	12.43	-0.24	-21.07	0.06
Malta	-0.11	0.00	-0.33	0.01	-0.44	0.00
Netherlands	-76.99	0.26	-78.61	1.55	-155.60	0.46
Poland	-998.58	3.43	590.93	-11.64	-407.65	1.19
Portugal	-3290.38	11.32	-197.29	3.89	-3487.67	10.21
Republic of Ireland	-448.98	1.54	-155.94	3.07	-604.92	1.77
Romania	-1588.87	5.46	367.26	-7.23	-1221.61	3.58
Slovakia	0.00	0.00	0.02	0.00	0.02	0.00
Slovenia	-35.57	0.12	7.95	-0.16	-27.63	0.08
Spain	-12900.44	44.37	-2513.61	49.50	-15414.06	45.13
Sweden	-61.36	0.21	65.22	-1.28	3.85	-0.01
Switzerland	-221.51	0.76	56.61	-1.11	-164.90	0.48
United Kingdom	-582.80	2.00	-530.31	10.44	-1113.11	3.26
Total	-29074.03	100.00	-5077.70	100.00	-34151.73	100.00

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3.4 Potential impact of LULUCF inventory

3.4.1 Understanding baseline

EU's AFOLU sector, which combines agriculture and LULUCF, experienced a net reduction of 40.64% in emissions/removals, dropping from 330.2 Mt CO_2 eq in 1990 to 196 Mt CO_2 eq in 2020. Whereas for LULUCF sector, which AFOLU without agriculture, there was a notable decrease in carbon removals by 12.80%, with total net emissions/removals changing from -201 Mt CO_2 eq in 1990 to -226 Mt CO_2 eq in 2020 (Figure 23).

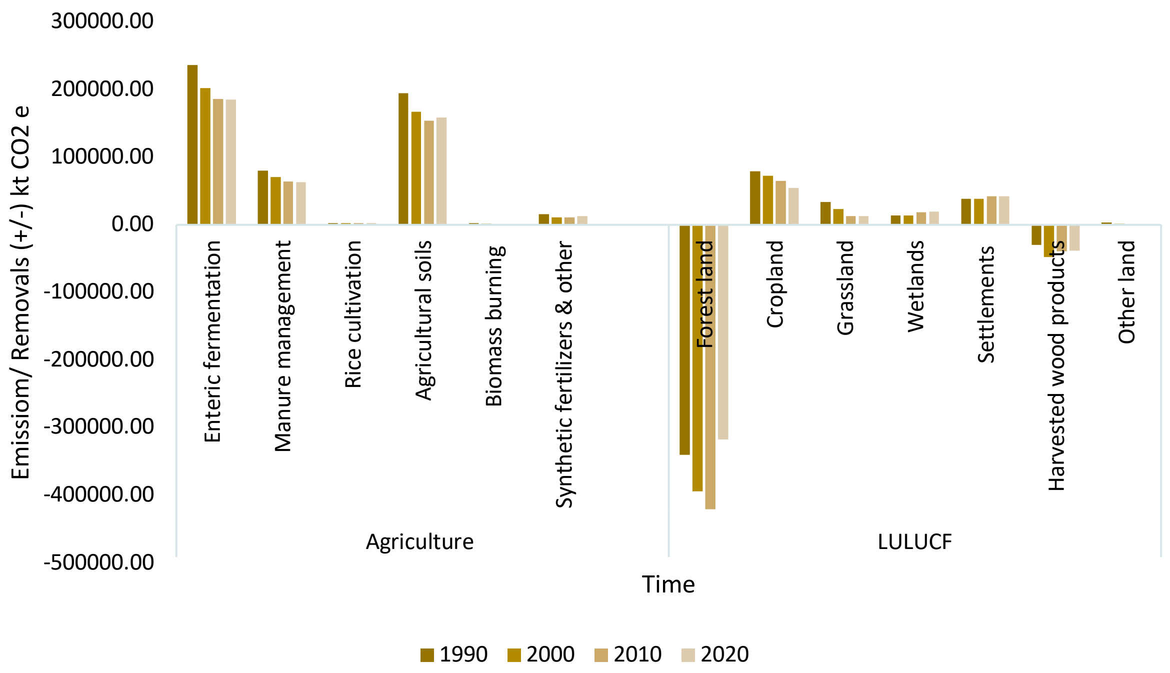

Figure 23. EU GHG emissions and removals figures 1990-2020

This reduction in removals is primarily driven by decreased sequestration by Forest Land category, where removals increased by 6.45%. Despite this, Forest Land remains a significant carbon sink. In contrast, Grassland saw the largest decrease in emissions at 61.94%, which contributed to the overall reduction in net emissions.

The reduction was primarily driven by decreases in emissions from Agricultural Soils (18.57%), Enteric Fermentation (21.56%), and Manure Management (21.16%). Biomass Burning saw the most substantial decline at 54.46%, while emissions from Synthetic Fertilisers & Other fell by 19.07%. However, these reductions are offset by the increased relative importance of agricultural emissions in the total emissions profile, highlighting the ongoing challenge of mitigating emissions in this sector.

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3.4.2 The impacts of agroforestry areas on LULUCF inventory

In 2018, the combined study areas of the EU, UK, and Switzerland reported approximately 4.5 gigatonnes of CO_2 eq GHG emissions across all sectors. LULUCF sector acted as a net GHG sink, removing around 228 Mt CO_2 eq, which represents about -5% of total emissions. Meanwhile, the cropland sub-category accounted for around 16.7 million tonnes of GHG emissions Mt CO_2 eq.

Since agroforestry is normally considered under the cropland category, the estimates suggesting the classified silvopastoral and silvoarable areas have the potential to further enhance the sector's GHG mitigation, by sequestering an additional -34.1 Mt CO_2 eq. This would increase the sector’s GHG removal by roughly 14.9%. Consequently, agroforestry could not only offset all emissions from cropland but also could contribute to mitigating approximately 14% of emissions from the grassland category.

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4 Conclusion

A total of **61 million hectares** (Mha) of agroforestry practices have been identified across the EU, UK, and Switzerland, with land use primarily determining these areas. Of this, around 15 Mha are classified as common agroforestry areas, while the remaining land is categorised as small woody feature agroforestry systems. Approximately 10 Mha, or most common agroforestry areas, are made up of silvopastoral and silvoarable systems. These systems are largely concentrated in three key biogeographical regions: Atlantic**,** Continental, and Mediterranean — which together cover about 67.9% of European territory.

Out of the identified common agroforestry areas, 61.31% (approximately 6.2 Mha) were classified as silvopastoral systems, while the remaining 38.69% (3.9 Mha) were categorised as silvoarable systems. These systems are vital for carbon sequestration, with silvopastoral systems showing carbon removal rates between 1.79 to 2.69 t C ha^{-1} $year^{-1}$**,** supported by tree densities ranging from 156 to 174 trees ha^{-1}**,** and tree ages spanning 26 to 68 years. On the other hand, silvoarable systems have slightly different carbon removal rates, ranging from 0.78 to 3.83 t C ha^{-1} $year^{-1}$, with a tree density of 92 to 126 trees ha^{-1}, and ages varying from 18 to 92 years.

While these agroforestry systems contribute significantly to carbon removal, they also emit greenhouse gases due to management activities such as pruning, thinning, and grazing. The emission rates are around 5.73 and 4.7 t CO_2 eq ha^{-1} $year^{-1}$ for silvopastoral and silvoarable systems respectively. Overall, these systems collectively contribute by removing and emitting 88.66 and 54.3 million t CO_2 eq, leading to a total net emission of -34.1 million t CO_2 eq.

This suggests that, in 2018, the estimated silvopastoral and silvoarable agroforestry areas have the potential to further enhance LULCF sector GHG mitigation by sequestering an additional **-**34.1 Mt CO_2 eq. This would increase the sector's GHG removal by roughly 14.9%. Consequently, agroforestry could potentially not only offset all emissions from cropland but also contribute to mitigating approximately 14% of emissions from the grassland category.

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5 References

Aertsens, J., De Nocker, L., & Gobin, A. (2013). Valuing the carbon sequestration potential for European agriculture. *Land Use Policy*, *31*, 584–594. https://doi.org/10.1016/j.landusepol.2012.09.003

Augère-Granier, M. L. (2020). Agroforestry in the European Union. *European Parliamentary Research Service, EU*, *PE 651.982*, 1–11.

Augère-Granier, M. L. (2020). *Agroforestry in the European Union*. https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/651982/EPRS_BRI(2020)651982_EN.pdf

Batista, F., & Pigaiani, C. (2021a). *LUISA Base Map 2018*. European Commission, Joint Research Centre (JRC). https://data.jrc.ec.europa.eu/dataset/51858b51-8f27-4006-bf82-53eba35a142c

Batista, F., & Pigaiani, C. (2021b). *LUISA Base Map 2018*. European Commission, Joint Research Centre (JRC). https://data.jrc.ec.europa.eu/dataset/51858b51-8f27-4006-bf82-53eba35a142c

Carré, F., Hiederer, R. , Blujdea, V., & Koeble, R. (2010). *Background Guide for the Calculation of Land Carbon Stocks in the Biofuels Sustainability Scheme Drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. https://doi.org/10.2788/34463

Copernicus Land Monitoring Service. (2023a). *CLC 2018*. https://land.copernicus.eu/pan-european/corine-land-cover/clc2018

Copernicus Land Monitoring Service. (2023b). *High Resolution Layers*. https://land.copernicus.eu/pan-european/high-resolution-layers

De Klein, C., Novoa, R. S. A. , Ogle, S., Smith, K. A. , Rochette, P., Wirth, T. C., McConkey, B. G. , Mosier, A., & Rypdal, K. (2006). *N2O EMISSIONS FROM MANAGED SOILS, AND CO2 EMISSIONS FROM LIME AND UREA APPLICATION, Volume 4: Agriculture, Forestry and Other Land Use, 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Vol. 4). https://www.ipcc-nggip.iges.or.jp/public/2006gl/

De Rosa, D., Ballabio, C., Lugato, E., Fasiolo, M., Jones, A., & Panagos, P. (2023). Soil organic carbon stocks in European croplands and grasslands: How much have we lost in the past decade? *Glob Chang Biol*, *30*(1), e16992. https://doi.org/10.1111/gcb.16992

De-Sousa, K. T., Deniz, M., Hill, J. A. G., Dittrich, J. R., & Hötzel, M. J. (2023). Tree arrangements for silvopastoral system: livestock advisors' knowledge and attitudes. *Agroforestry Systems*, *97*(6), 1143–1156. https://doi.org/10.1007/s10457-023-00853-z

Domke, G., Brandon, A., Diaz-Lasco, R., Federici, S., Garcia-Apaza, E., Grassi, G., Gschwantner, T., Herold, M., Hirata, Y., Kasimir, Å., James Kinyanjui, M., Krisnawati, H., Lehtonen, A., Malimbwi, R. E., Niinistö, S., Michael Ogle, S., Paul, T., Ravindranath, N. H., Rock, J., … Verchot, L. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Forest Land*.

Eichhorn, M. P., Paris, P., Herzog, F., Incoll, L. D., Liagre, F., Mantzanas, K., Mayus, M., Moreno, G., Papanastasis, V. P., Pilbeam, D. J., Pisanelli, A., & Dupraz, C. (2006). Silvoarable Systems in Europe – Past, Present and Future Prospects. *Agroforestry Systems*, *67*(1), 29–50. https://doi.org/10.1007/s10457-005-1111-7

EU. (2010). COMMISSION DECISION of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC (notified under document C(2010) 3751) (2010/335/EU). *Official Journal of the European Union*, *17*, 19–41. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:151:0019:0041:EN:PDF

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

EU. (2013). REGULATION (EU) No 1305/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005. *Official Journal of the European Union*, 347–548. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R1305

Fornara, D. A., Olave, R., Burgess, P., Delmer, A., Upson, M., & McAdam, J. (2017). Land use change and soil carbon pools: evidence from a long-term silvopastoral experiment. *Agroforestry Systems*, *92*(4), 1035–1046. https://doi.org/10.1007/s10457-017-0124-3

Fotakis, D., Karmiris, I., Kiziridis, D. A., Astaras, C., & Papachristou, T. G. (2024). Social-Ecological Spatial Analysis of Agroforestry in the European Union with a Focus on Mediterranean Countries. *Agriculture*, *14*(8), 1222. https://doi.org/10.3390/agriculture14081222

Gao, Y., & Cabrera Serrenho, A. (2023). Greenhouse gas emissions from nitrogen fertilizers could be reduced by up to one-fifth of current levels by 2050 with combined interventions. *Nat Food*, *4*(2), 170–178. https://doi.org/10.1038/s43016-023-00698-w

Gerry, L., Sonja, K., & Christian, D. (2020). *Agroforestry for Carbon Farming in Europe. EURAF Policy Briefing No 8 v4. (1/9/20, 2/12/21, 3/4/22, 28/3/24)* (Vol. 2024, Issue 15 June). EURAF. https://zenodo.org/records/10890282

Hatfield, J. L., Johnson, D. E., Bartram, D., Gibb, D., & Martin, J. H. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories EMISSIONS FROM LIVESTOCK AND MANURE MANAGEMENT*. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

Hiederer, R., Ramos, F., Capitani, C., Koeble, R., Blujdea, V., Gomez, O., Mulligan, D., & Marelli, L. (2010). *Biofuels: a New Methodology to Estimate GHG Emissions from Global Land Use Change, A methodology involving spatial allocation of agricultural land demand and estimation of CO2 and N2O emissions*. https://doi.org/10.2788/48910

ICRAF, A. Steppler, H., & Nair, P. K. R. (1987). *Agroforestry a decade of development*. International Council for Research in Agroforestry (ICRAF). https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=66a9638f37bdcdb68a484271e807a4434748fdcd#page=12

King, K. F. S., & Chandler, M. T. (1978). *The Wasted Lands THE PROGRAMME OF WORK OF ICRAF*. International Council for Research in Agroforestry. https://apps.worldagroforestry.org/downloads/Publications/PDFS/B01036.pdf

Krug, T., Lasco, R. D., Ogle, S., Raison Yue Li, J., Martino, D. L., McConkey, B. G., Smith, P., & Wanja Karunditu, M. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, , Agriculture, Forestry and Other Land Use, GRASSLAND*. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

Michael, den H., Moreno, G., Mosquera-Losada, R. M., Palma, J. H. N., Sidiropoulou, A., Santiago Freijanes, J. J., Crous-Duran, J., Paulo, J. A., Tomé, M., Pantera, A., Papanastasis, V. P., Mantzanas, K., Pachana, P., Papadopoulos, A., Plieninger, T., & Burgess, P. J. (2017). Current extent and stratification of agroforestry in the European Union. *Agriculture, Ecosystems & Environment*, *241*, 121–132. https://doi.org/10.1016/j.agee.2017.03.005

Michael, den H., Paul, B., María Rosa, M.-L., Felix, H., Tibor, H., Matthew, U., Iida, V., & Adolfo, R. (2015). *Preliminary stratification and quantification of agroforestry in Europe. Milestone Report 1.1 for EU FP7 Research Project: AGFORWARD 613520* (24 April 2015). https://www.agforward.eu/preliminary-stratification-and-quantification-of-agroforestry-in-europe.html

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

Mosquera-Losada, M. R., McAdam, J. H., Romero-Franco, R., Santiago-Freijanes, J. J., & Rigueiro-Rodríguez, A. (2009). Definitions and Components of Agroforestry Practices in Europe. In J. and M.-L. M. R. Rigueiro-Rodróguez Antonio and McAdam (Ed.), *Agroforestry in Europe: Current Status and Future Prospects* (pp. 3–19). Springer Netherlands. https://doi.org/10.1007/978-1-4020-8272-6_1

Mosquera-Losada, M. R., Santiago-Freijanes, J. J., Rois-Díaz, M., Moreno, G., den Herder, M., Aldrey-Vázquez, J. A., Ferreiro-Domínguez, N., Pantera, A., Pisanelli, A., & Rigueiro-Rodríguez, A. (2018a). Agroforestry in Europe: A land management policy tool to combat climate change. *Land Use Policy*, *78*, 603–613. https://doi.org/https://doi.org/10.1016/j.landusepol.2018.06.052

Mosquera-Losada, M. R., Santiago-Freijanes, J. J., Rois-Díaz, M., Moreno, G., den Herder, M., Aldrey-Vázquez, J. A., Ferreiro-Domínguez, N., Pantera, A., Pisanelli, A., & Rigueiro-Rodríguez, A. (2018b). Agroforestry in Europe: A land management policy tool to combat climate change. *Land Use Policy*, *78*, 603–613. https://doi.org/https://doi.org/10.1016/j.landusepol.2018.06.052

Mosquera-Losada, M. R., Santos, M. G. S., Gonçalves, B., Ferreiro-Domínguez, N., Castro, M., Rigueiro-Rodríguez, A., González-Hernández, M. P., Fernández-Lorenzo, J. L., Romero-Franco, R., Aldrey-Vázquez, J. A., Sobrino, C. C., García-Berrios, J. J., & Santiago-Freijanes, J. J. (2023). Policy challenges for agroforestry implementation in Europe. *Frontiers in Forests and Global Change*, *6*. https://doi.org/10.3389/ffgc.2023.1127601

Nair, P. K. R., Kumar, B. M., & Nair, V. D. (2021). Definition and Concepts of Agroforestry. In *An Introduction to Agroforestry: Four Decades of Scientific Developments* (pp. 21–28). Springer International Publishing. https://doi.org/10.1007/978-3-030-75358-0_2

Perez-Priego, O., El-Madany, T. S., Migliavacca, M., Kowalski, A. S., Jung, M., Carrara, A., Kolle, O., Martín, M. P., Pacheco-Labrador, J., Moreno, G., & Reichstein, M. (2017). Evaluation of eddy covariance latent heat fluxes with independent lysimeter and sapflow estimates in a Mediterranean savannah ecosystem. *Agricultural and Forest Meteorology*, *236*, 87–99. https://doi.org/10.1016/j.agrformet.2017.01.009

Quandt, A., Neufeldt, H., & Gorman, K. (2023). Climate change adaptation through agroforestry: opportunities and gaps. *Current Opinion in Environmental Sustainability*, *60*, 101244. https://doi.org/https://doi.org/10.1016/j.cosust.2022.101244

Rigueiro-Rodríguez, A., Mosquera-Losada, M. R., & Fernández-Núñez, E. (2011). Afforestation of agricultural land with Pinus radiata D. don and Betula alba L. in NW Spain: Effects on soil PH, understorey production and floristic diversity eleven years after establishment. *Land Degradation & Development*, *23*(3), 227–241. https://doi.org/10.1002/ldr.1072

Rodel Lasco, A. D., Ogle, S., Raison, J., Verchot ICRAF, L., Wassmann, R., Yagi Sumana Bhattacharya, K., Brenner, J. S., Partson Daka, J., González, S. P., Krug, T., Li, Y., Martino, D. L., McConkey, B. G., Smith, P., Tyler, S. C., Zhakata, W., Sass, R. L., & Yan, X. (2006). *Agriculture, Forestry and Other Land Use 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Cropland*. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Rubio-Delgado, J., Schnabel, S., Burgess, P. J., & Burbi, S. (2023). Reduced grazing and changes in the area of agroforestry in Europe. *Frontiers in Environmental Science*, *11*. https://doi.org/10.3389/fenvs.2023.1258697

Serra, J. (1983). *Image Analysis and Mathematical Morphology*. Academic Press. https://doi.org/10.1002/cyto.990040213

Simone, B., Yujuan, C., & O, F. A. (2018). *Agroforestry*. FAO, Forestry Department.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

Skovsgaard, J. P., Johansson, U., Holmström, E., Tune, R. M., Ols, C., & Attocchi, G. (2021). Effects of Thinning Practice, High Pruning and Slash Management on Crop Tree and Stand Growth in Young Even-Aged Stands of Planted Silver Birch (Betula pendula Roth). *Forests*, *12*(2). https://doi.org/10.3390/f12020225

Susanne Schnabel, J. R. D., Francisco Lavado Contador, Marco Van De Wiel, & Eden, J. (2020). *Impact of climate change on mixed farming and agroforestry systems in Europe*. EU.

Terasaki Hart, D. E., Yeo, S., Almaraz, M., Beillouin, D., Cardinael, R., Garcia, E., Kay, S., Lovell, S. T., Rosenstock, T. S., Sprenkle-Hyppolite, S., Stolle, F., Suber, M., Thapa, B., Wood, S., & Cook-Patton, S. C. (2023). Priority science can accelerate agroforestry as a natural climate solution. *Nature Climate Change*, *13*(11), 1179–1190. https://doi.org/10.1038/s41558-023-01810-5

Tolan, J., Yang, H. I., Nosarzewski, B., Couairon, G., Vo, H. V., Brandt, J., Spore, J., Majumdar, S., Haziza, D., Vamaraju, J., Moutakanni, T., Bojanowski, P., Johns, T., White, B., Tiecke, T., & Couprie, C. (2024). Very high-resolution canopy height maps from RGB imagery using self-supervised vision transformer and convolutional decoder trained on aerial lidar. *Remote Sensing of Environment*, *300*, 113888. https://doi.org/10.1016/J.RSE.2023.113888

UNFCCC. (2022, May 15). *National Inventory Submissions 2022*. https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/submissions/national-inventory-submissions-2022

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6 Appendix

6.1 EU's LULUCF emission and removal data obtained from Common Report format (UNFCCC, 2022)

Table 32. EU GHG emissions and removals figures 1990-2020 (UNFCCC, 2022)

		1990	2000	2010	2020	CHANGE 1990 -2020
		Emission (+) and removals (-) different sectors in kt CO_2 eq				
AGRICULTURE	Enteric fermentation	235806.77	201847.95	185773.22	184956.48	-21.56
	Manure management	80339.95	71001.44	63673.23	63341.80	-21.16
	Rice cultivation	2817.17	2479.99	2835.57	2441.02	-13.35
	Agricultural soils	194857.73	167224.88	153856.33	158676.05	-18.57
	Biomass burning	2103.93	1958.68	823.42	958.06	-54.46
	Synthetic fertilizers & other	15407.87	10980.61	11300.48	12469.28	-19.07
	Total Agriculture sector	531333.43	455493.55	418262.25	422842.69	-20.42
	% of sector from Total	9.77	9.37	9.38	12.18	56.55
LULUCF	Forest land	-339643.94	-394104.76	-419972.18	-317735.62	-6.45
	Cropland	79512.77	72277.00	65322.94	54266.60	-31.75
	Grassland	34125.62	23231.42	12936.03	12989.86	-61.94
	Wetlands	13543.04	14155.01	18316.60	19580.54	44.58
	Settlements	38400.14	38789.08	42405.39	41906.52	9.13
	Harvested wood products	-30083.97	-47841.98	-39085.25	-38404.83	27.66
	Other land	3064.24	1473.12	238.71	576.42	-81.19
	Total LULUCF sector	-201082.09	-292021.11	-319837.75	-226820.52	12.80
	% of sector from Total	-3.70	-6.01	-7.17	-6.53	-35.45
AFOLU	LULUCF + Agriculture	330251.34	163472.43	98424.50	196022.17	-40.64
	% of sector from Total	6.08	3.36	2.21	5.64	
TOTAL	All sectors (AFOLU and Non AFOLU)	5435695.645	4860189	4460179	3472985	-36.11

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6.2 Abstract of a proposed manuscript

Proposed title: Agroforestry systems for climate change mitigation with an integrated management approach in Europe

EDRIS S.[1], GABOUREL A.[2], OLAVE R.[1], SCHNABEL S.[2], LAVADO CONTADOR JF[2],

[1]Agri-Environment Branch - EMSD, Agri-Food and Biosciences Institute, 18a Newforge Lane, Belfast, BT9 5PX, Northern Ireland, UK
[2]INTERRA Research Institute, University of Extremadura, Spain.

Corresponding author: **salim.edris@afbini.gov.uk**

Agroforestry systems are recognized worldwide for their potentials to mitigate greenhouse gas (GHG) emissions and enhance carbon sequestration. The aim of this paper was to estimate GHG emissions and removals of two types of agroforestry systems (Silvopasture and Silvoarable) by mapping their areas within the main European biogeographical regions as well as identifying management activities associated with the systems

The study identified a total of 61 million hectares of agroforestry areas across the EU, UK, and Switzerland, with 15 million hectares classified as common agroforestry systems, comprising roughly 6.2 million hectares of potential silvopastoral systems and 3.9 million hectares of silvoarable systems. These systems, predominantly exist within the EU3bR, representing around 67.84% of the total mapped common agroforestry areas. Biomass carbon removal analysis revealed that silvopastoral systems, with a higher tree density (156 –174 trees ha^{-1}) and older tree age (26–68 years), exhibit carbon removal rates of 2.69–3.21 t C ha^{-1}year^{-1}, while silvoarable systems show slightly lower removal rates of 0.78–3.83 t C ha^{-1}year^{-1}, with a density of 92–126 trees ha^{-1}. Despite their carbon removal potentials, these land use systems also emit GHG emissions through management activities such as thinning, pruning, grazing, and fertilization. On average, silvopastoral systems emit approximately 5.73 t CO_2 eq ha^{-1}year^{-1}, while silvoarable systems contribute by 4.7 t CO_2 eq ha^{-1}year^{-1}. Collectively these systems remove approximately 88.66 million tonnes of CO_2 year^{-1} while around emitting 54.3 million tonnes CO_2 eq year^{-1}, resulting in a net emission of -34.1 million tonnes of CO_2 eq year^{-1}. From a land use, land-use change, and forestry (LULUCF) perspective, the combined EU, UK, and Switzerland regions reported 4.5 gigatonnes of CO_2 eq emissions in 2018, with the LULUCF sector acting as a net sink, removing 228 million tonnes CO_2 eq, equivalent to -5% of total emissions. Agroforestry, when integrated within the cropland sector, has the potential to further enhance the sector's GHG mitigation, potentially offsetting all cropland emissions and contributing to around 14% reduction in grassland emissions. These findings highlight the critical role of agroforestry systems in contributing to the EU's 2030 mitigation reduction targets and emphasize the need for integrated management approaches to maximize their environmental benefits.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

6.3 Factsheets

6.3.1 AGROMIX Factsheet Mapping agroforestry as a land use area for inclusion within the LULUCF in Europe

6.3.2 AGROMIX Factsheet Where to establish which agroforestry system?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

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Transforming landscapes

Mapping agroforestry as a land use area for inclusion within the LULUCF in Europe

Rodrigo Olave[1]
Anthony Gabourel Landaverde[2]
Salim Edris[1]
Susanne Schnabel[2]
Francisco Lavado-Contador[2]

[1]Agri-Environment Branch, Agri-Food and Biosciences Institute, Northern Ireland, UK
[2]INTERRA Research Institute, University of Extremadura, Spain.

Background

Accurate activity data is needed for the improvement of Greenhouse gas (GHG) inventories, particularly in the **Land Use, Land Use Change and Forestry (LULUCF) sector.** Identifying the spatial distribution and extent of land areas is a crucial step as all land must be assigned to one of six land use categories.

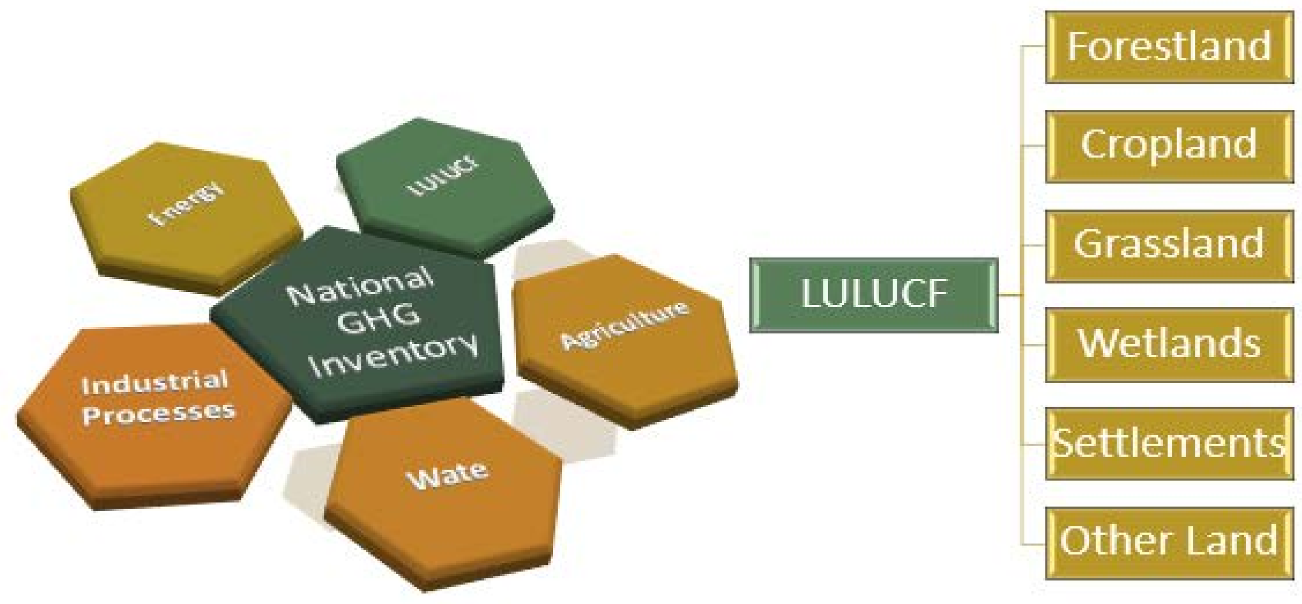
Agroforestry is a land use system where trees are grown in combination with arable crops and/or livestock on the same land unit and is currently included under the **cropland** category, without recognition of its potential contribution to emissions offsetting and carbon removals. However, technological advancements in remote imaging now allow detailed and accurate mapping of agroforestry as a distinct land use, and management practice, to be quantified accurately for effective GHG inventory management.

Aims and methodology

This research aimed to map agroforestry areas across Europe as a key step to define management practices and provide higher Tier emissions estimates for GHG sources and sinks using the Land-Use based Integrated Sustainability Assessment (LUISA) base map from 2018.

This spatial approach consisted of four steps:

- Selection of agricultural areas from LUISA dataset.
- Identification of trees present within agricultural areas using a tree cover density map.
- Removal of small woody features.
- Mapping of potential agroforestry areas via re-classification and creation of an agroforestry map across Europe.



Methodology used for identification of agroforestry areas

Selection of agricultural areas from 2018 LUISA map

↓

Selected classes

Grasslands	Permanent and temporary crops	Heterogeneous classes

↓

Combined with

Tree cover density map	Small woody features map

↓

Classes of tree cover density map

Between 1- 10%	Above 10%

↓

Identified agroforestry areas

Agroforestry areas by biogeographical regions	Agroforestry areas by countries

Typical agroforestry systems in the UK (left: silvopastoral system with poplar tees in rows) and Spain (right: silvopastoral system with dispersed cover of Holm oaks)

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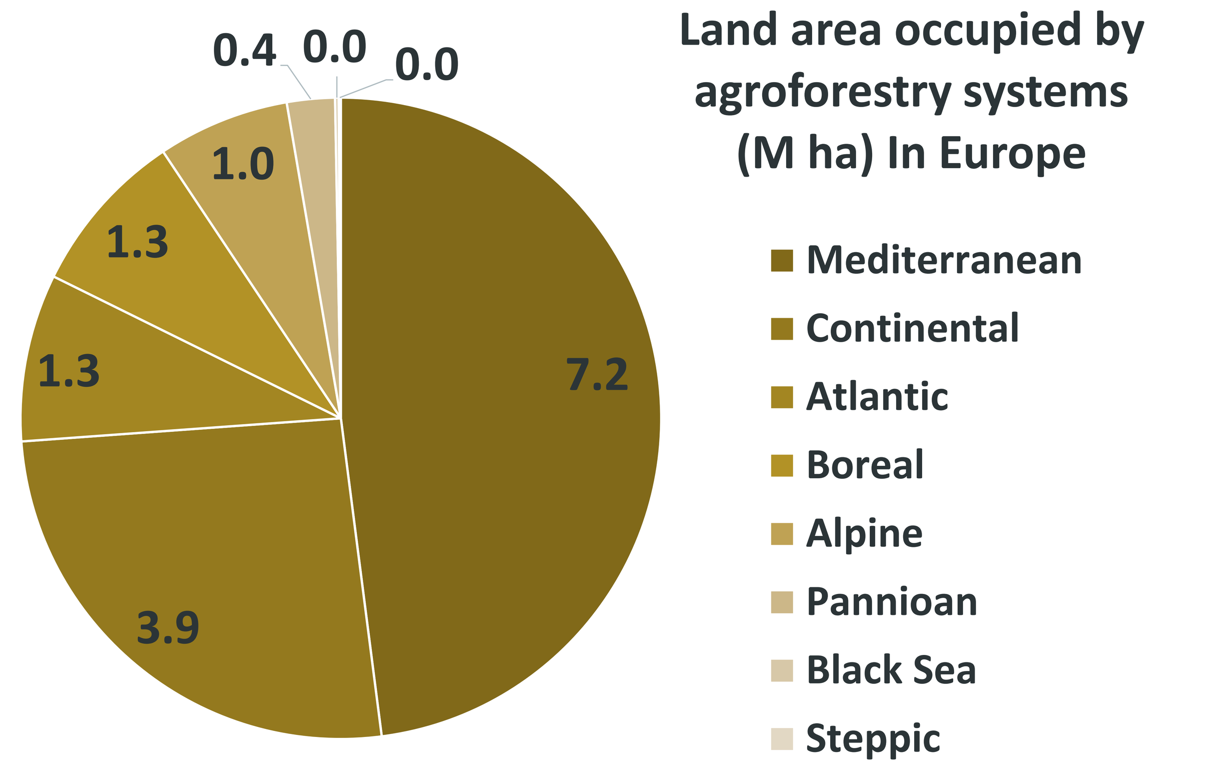
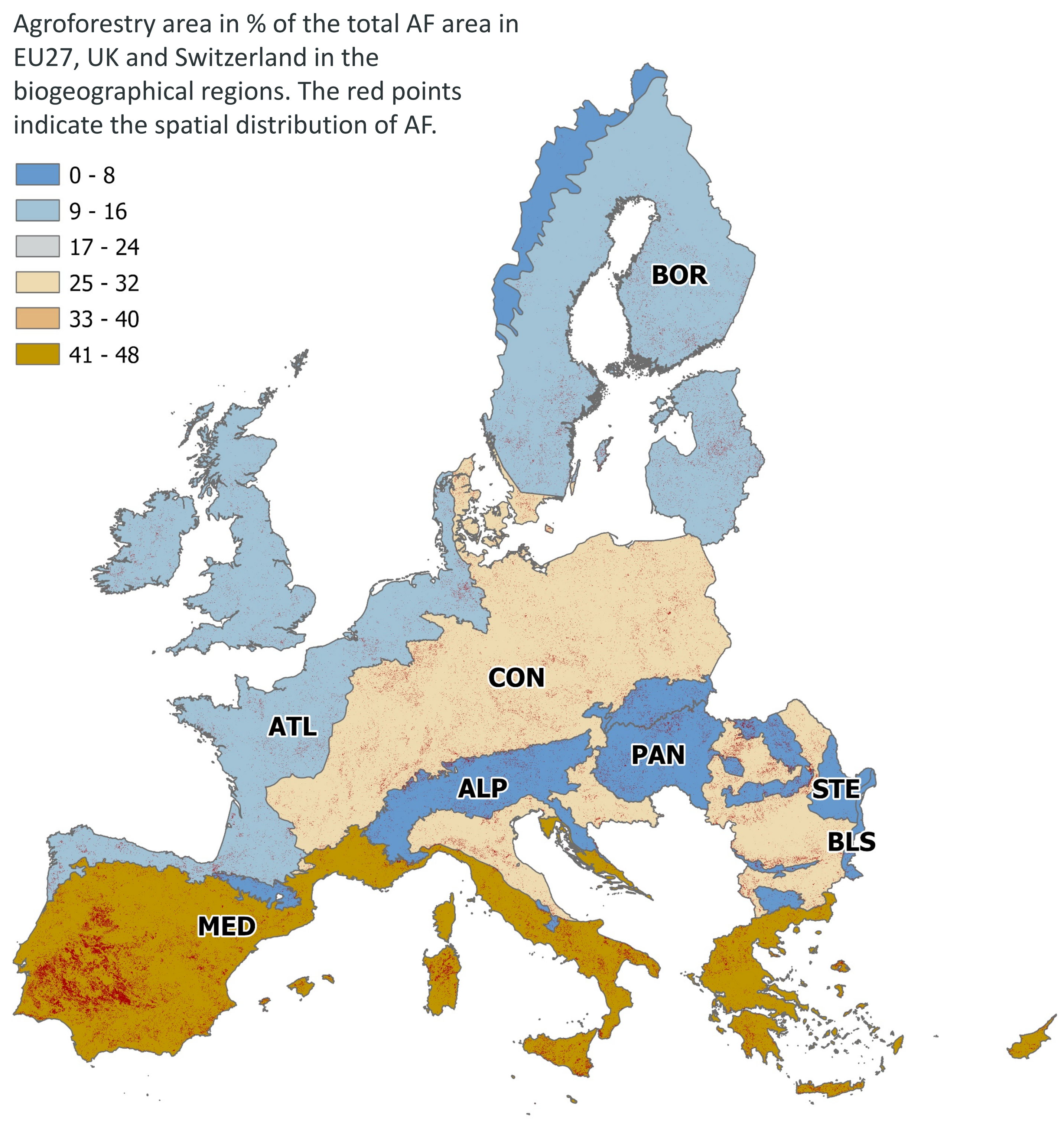
Key findings

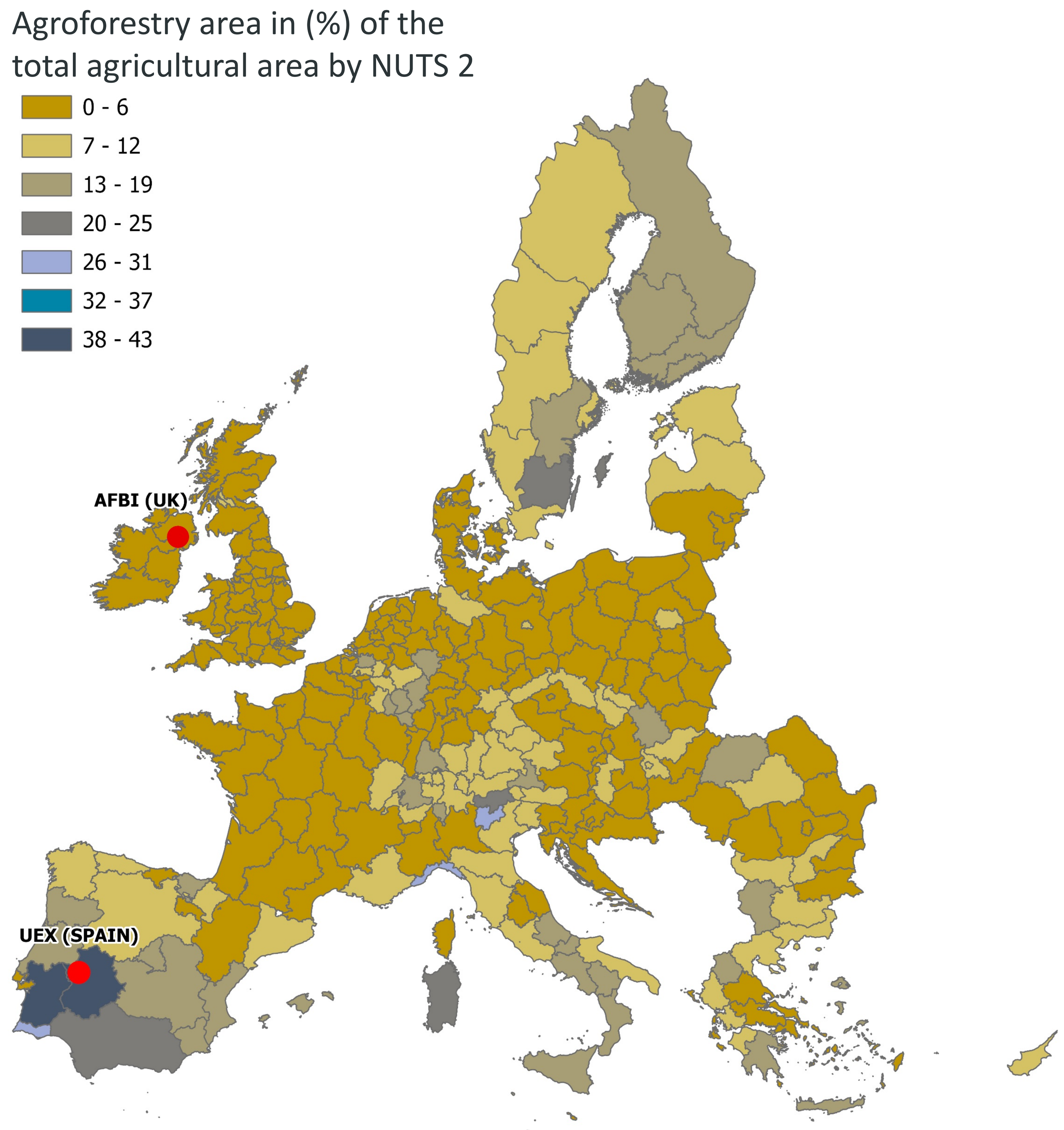
- A total of 15 M ha of agroforestry land areas have been identified within Europe.
- Approximately 48% (7.2 M ha) of the total represented agroforestry areas are located within the Mediterranean biogeographical region, followed by the Continental region (26%).
- The lowest proportion of agroforestry areas fall within the Black Sea and Steppic regions, representing 0.2% (27 k ha) and 0.1% (16 k ha) respectively.
- At country level, Spain accounts for 29% (4.4 M ha) of the total agroforestry area mapped, followed by Italy and Portugal with 10% (1.5 M ha) and 7% (1.0 M ha), respectively; these three Mediterranean countries appear to have a higher relative proportion of agroforestry as an agricultural land use.
- France, Germany, and Romania each contain 6% of the total agroforestry area mapped; accounting for 1.05, 1.04, and 0.9 M ha respectively.
- The remaining countries included in this study contain less than 1% of the total identified agroforestry area.





Outlook

- Providing an accurate estimation of land use area is a crucial step towards refining GHG inventories and carbon stock change factors.
- Agroforestry management practice activity data will be collated from agroforestry sites in UK and Spain to enable estimations of potential impact on LULUCF sector carbon stocks over time.
- The findings from this work provide a first key step towards a road map for potential inclusion of agroforestry land use systems into LULUCF sector inventories across Europe.



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Where to establish which agroforestry system? An interactive European map for decision support

Jo Smith, Ana Tomás and João Palma
MVARC, Mértola, Portugal
Anthony Gabourel-Landaverde, Susanne Schnabel, Francisco Lavado-Contador
INTERRA Research Institute, Universidad de Extremadura, Spain

Background

In the face of future climate challenges, it is of the utmost importance to drive the transition towards more resilient and efficient land use in Europe. Agroecological approaches such as agroforestry (the integration of trees, crops and/or livestock) have been recognized as "highly effective adaptation options that enhance resilience to climate change" (Bednar-Friedl et al., 2022[1]). But can we target the areas where such systems should be established? What kind of systems should be established to fit the farms' environment? And what are the particular characteristics or mechanisms of these agroecological systems that enhance their resilience, compared with conventional systems? As part of the AGROMIX project, an interactive land use change map has been created, building on solid scientific research, to help farmers, land managers and policy makers answer these questions.

LINK: https://agromixproject.eu/tools/agromix-land-use-change-interactive-map

The LUCIM - Land Use Change Interactive Map – offers two journeys. The first part explores a spatial approach to identifying target areas in Europe where introducing resilient and climate-smart agroforestry systems should have high priority to address existing environmental pressures, future climate change pressures and current socio-economic contexts. The second part establishes a guided cascade of context settings and suggests future scenarios of land use/resilience strategies where different models of agroforestry can be evaluated as pathways towards increasing the resilience of a farming system to climate change.

A tool for policy makers

Outcomes of the spatial modelling and land use change pathway development can be used to inform policy development to support the uptake of agroforestry in priority areas while addressing potential social and economic factors that may be barriers to, or conversely, opportunities for implementation.

[1] *Bednar-Friedl, B. et al. (2022) Europe. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. doi: 10.1017/9781009325844.015.*

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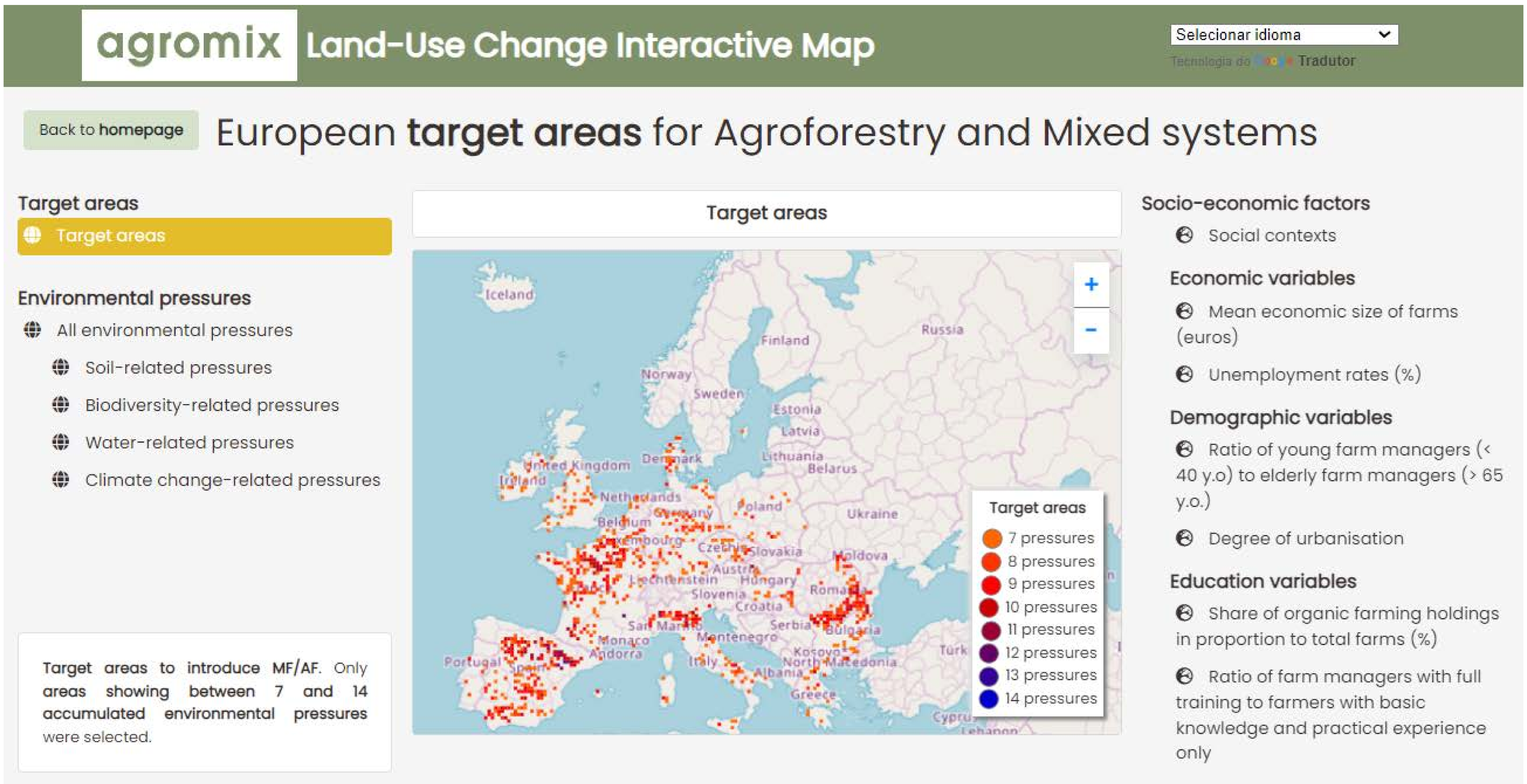
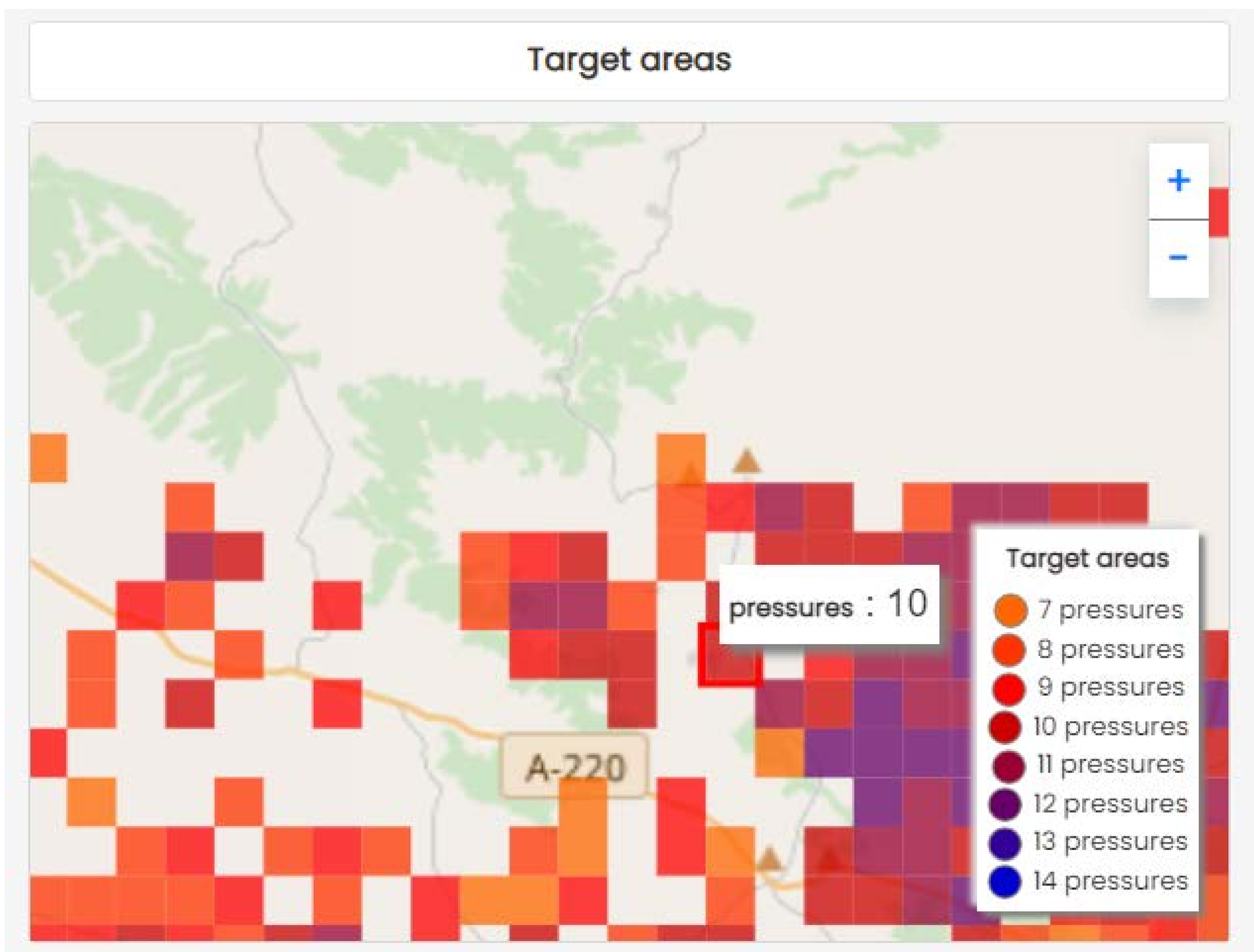
Where is the introduction of agroforestry most needed to address environmental risks and increase resilience to climate change?

Target areas

After combining environmental indicators related to water, biodiversity, climate and soil, a summary heat map highlights the intensity of a total of 14 environmental risks. Areas showing seven or more accumulated pressures are defined as target areas to introduce AF.



Zoom in to 1 km resolution and select a square to learn how many environmental pressures exist for that area.



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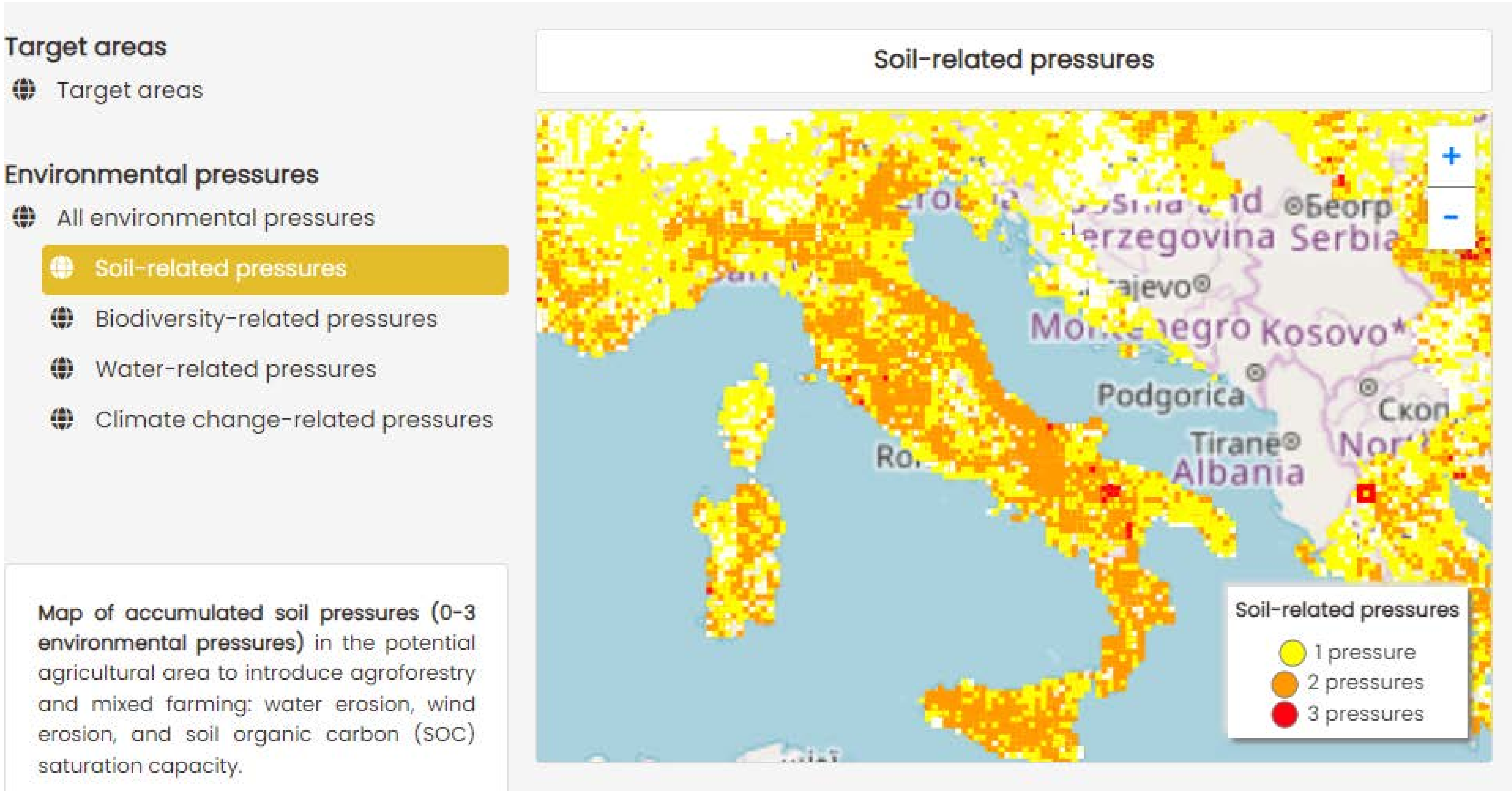
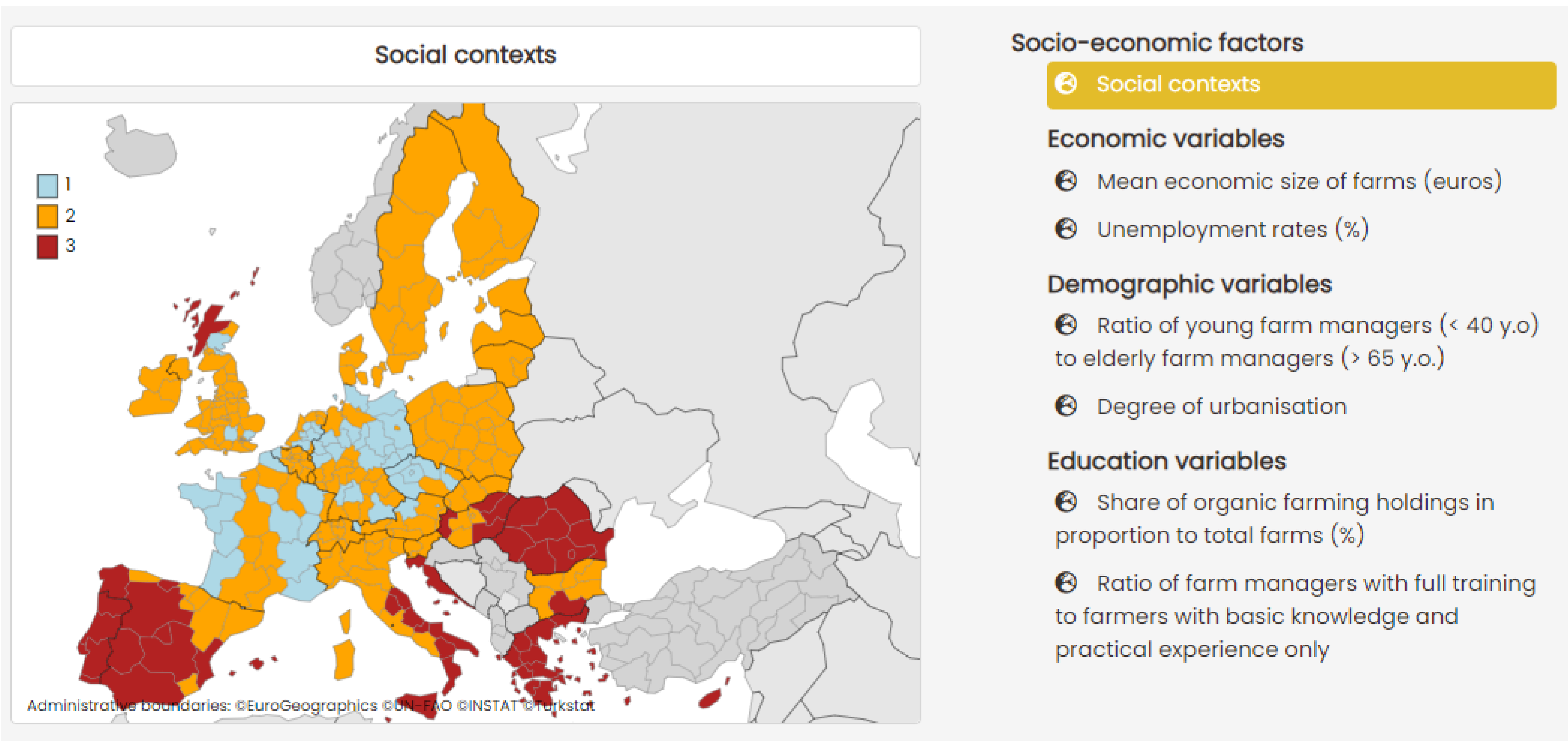
Environmental and climate pressures

To delve deeper into the different environmental and climate indicators underlying the final target areas, select and explore the ‘Environmental pressures’ maps. These pressures have been grouped into ‘Soil-related’, ‘Biodiversity-related’, ‘Water-related’ and ‘Climate-change-related’ pressures. More detailed information below the maps explains the rationale, data, thresholds and data sources behind the maps.



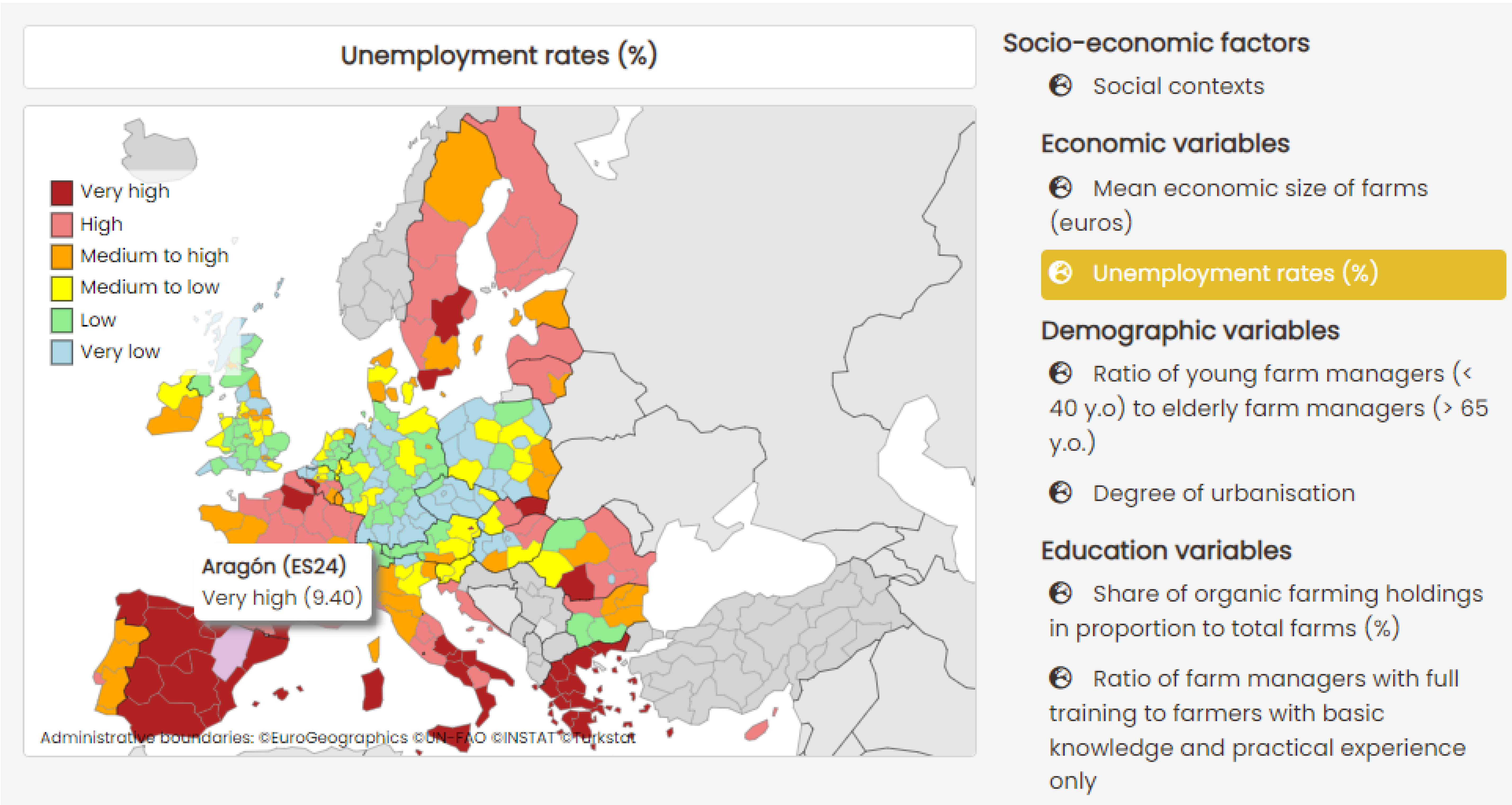
What are the socio-economic contexts of these target areas that need to be considered when developing policy support for implementing agroforestry?

Key to identifying appropriate support mechanisms for agroforestry is an understanding of the social and economic context of each region. Explore the ‘Social contexts’ map to identify regions where economic, demographic and education variables either converge to provide a positive environment for agroforestry establishment or constitute challenges where targeted policy support is essential.



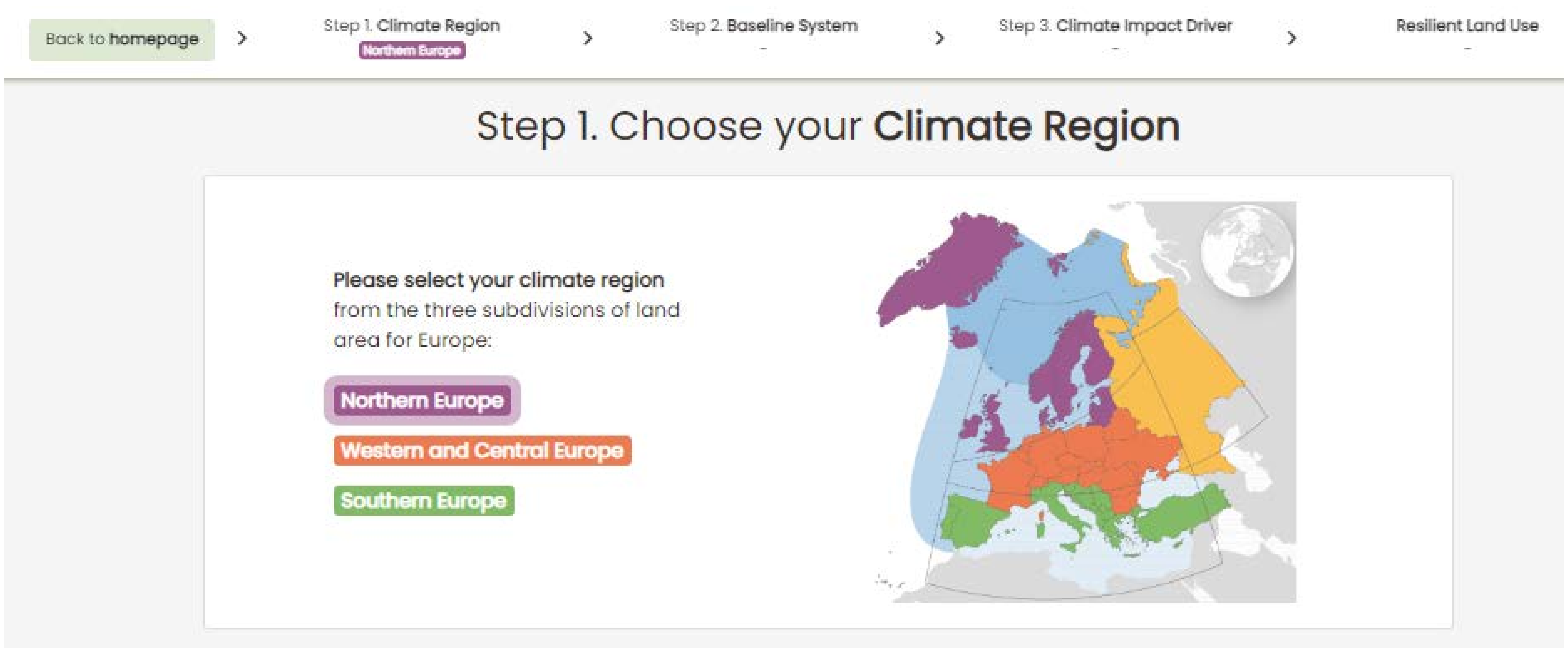
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 862993.

Discover the underlying variables by selecting one of the economic, demographic or education variables and hover over a region to identify it and its score. Detailed information on the data sets and thresholds of the indicators is provided underneath the maps.



What type of agroforestry could be introduced to increase resilience of farming systems to climate change in a particular region?

Step 1. Choose between one of the three regions: Northern Europe, Western and Central Europe or Southern Europe



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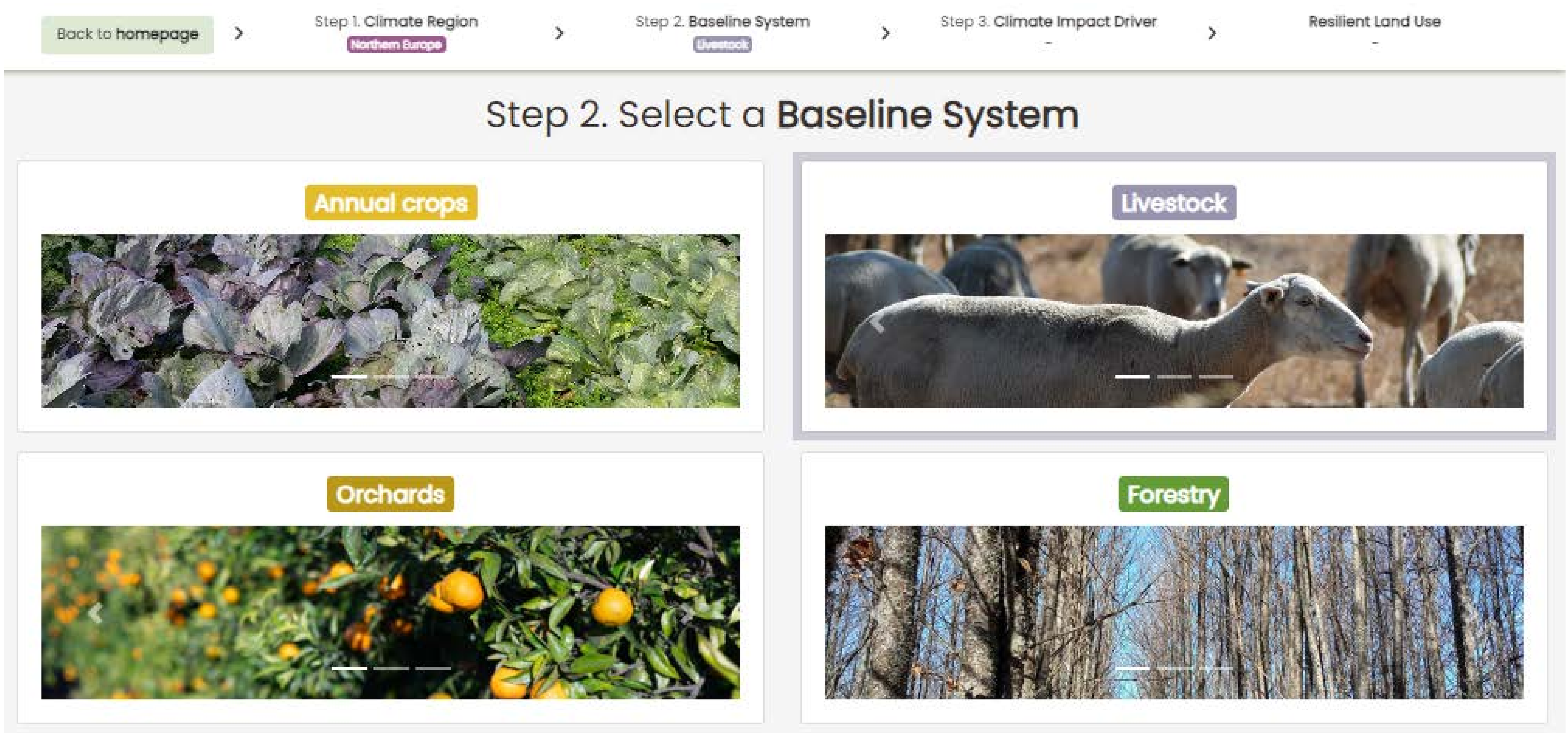
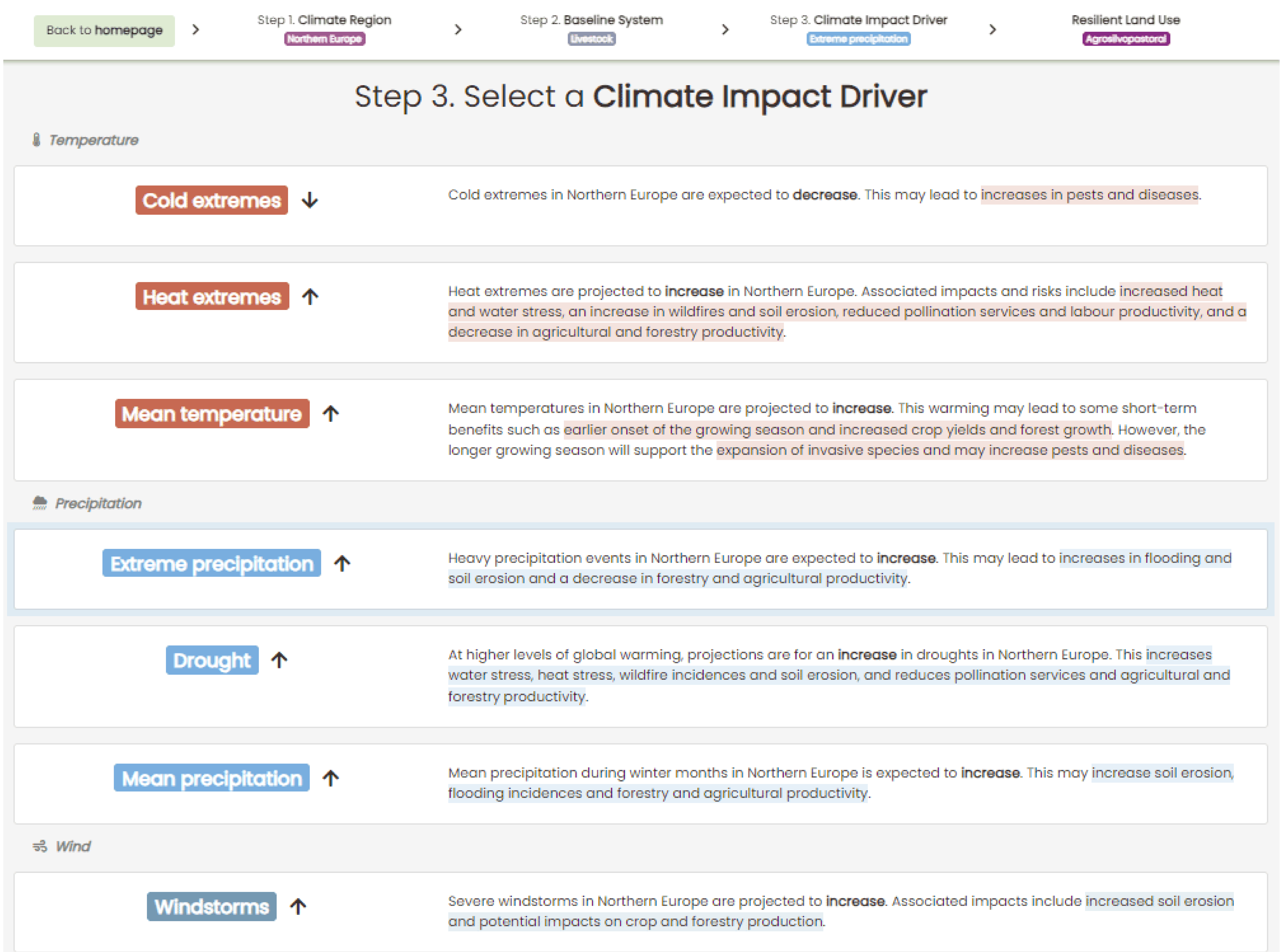
Step 2. Choose one of the four baseline systems: annual crops, livestock, orchards or forestry.



Step 3. Select the **climate impact driver** of interest between the seven available. Each climate impact driver has a short **description of its projected direction of change** and main consequences.



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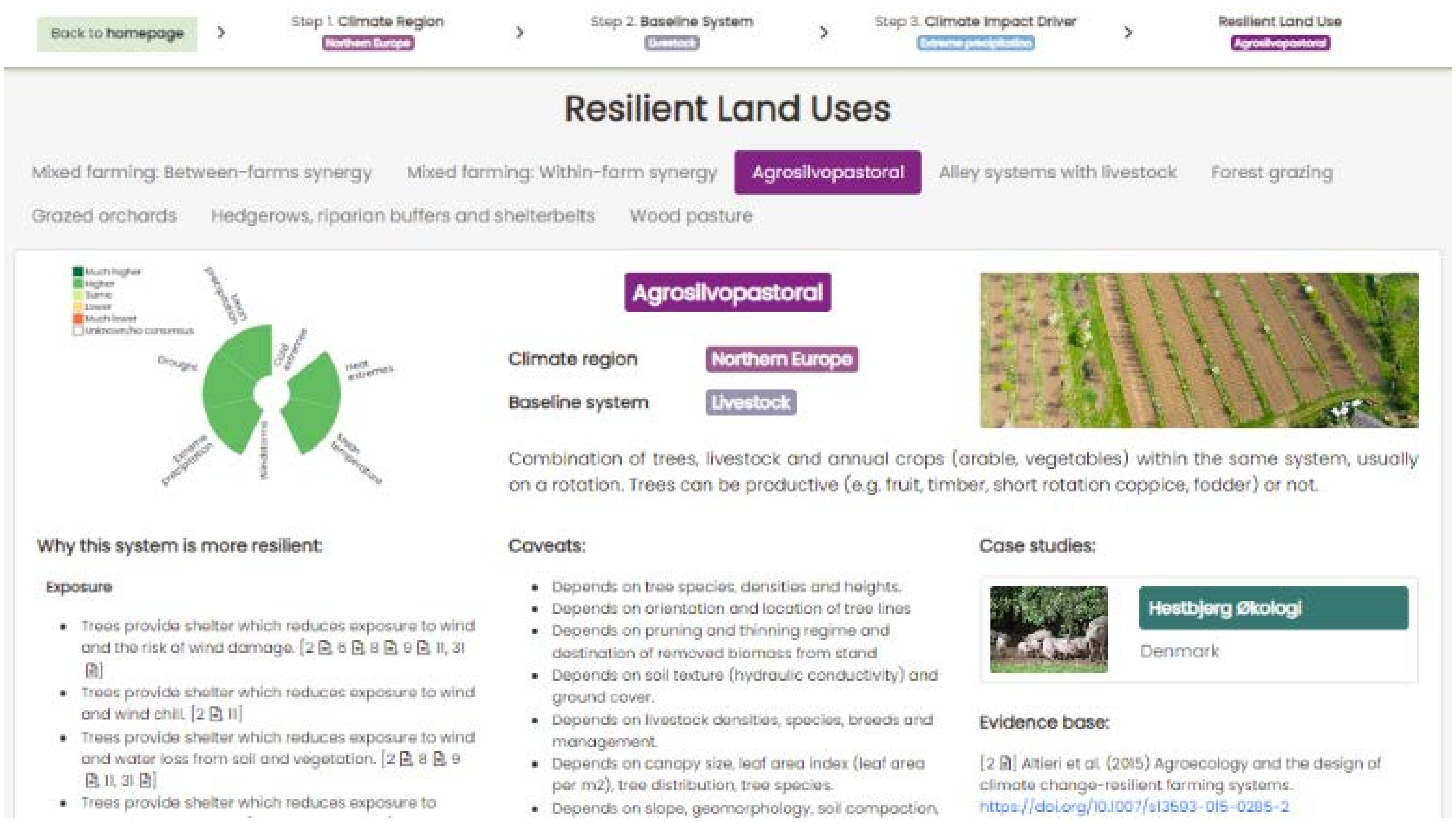
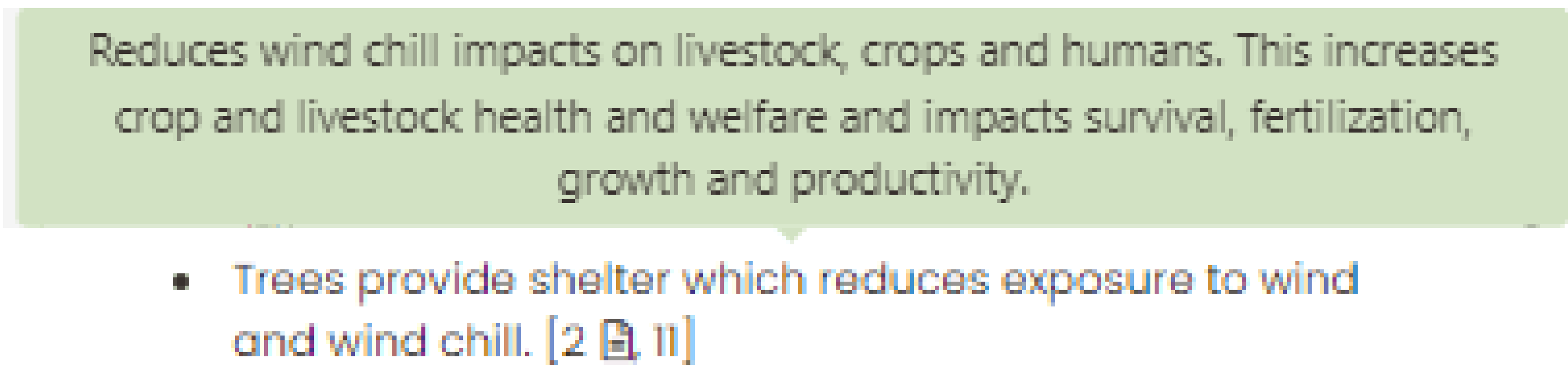
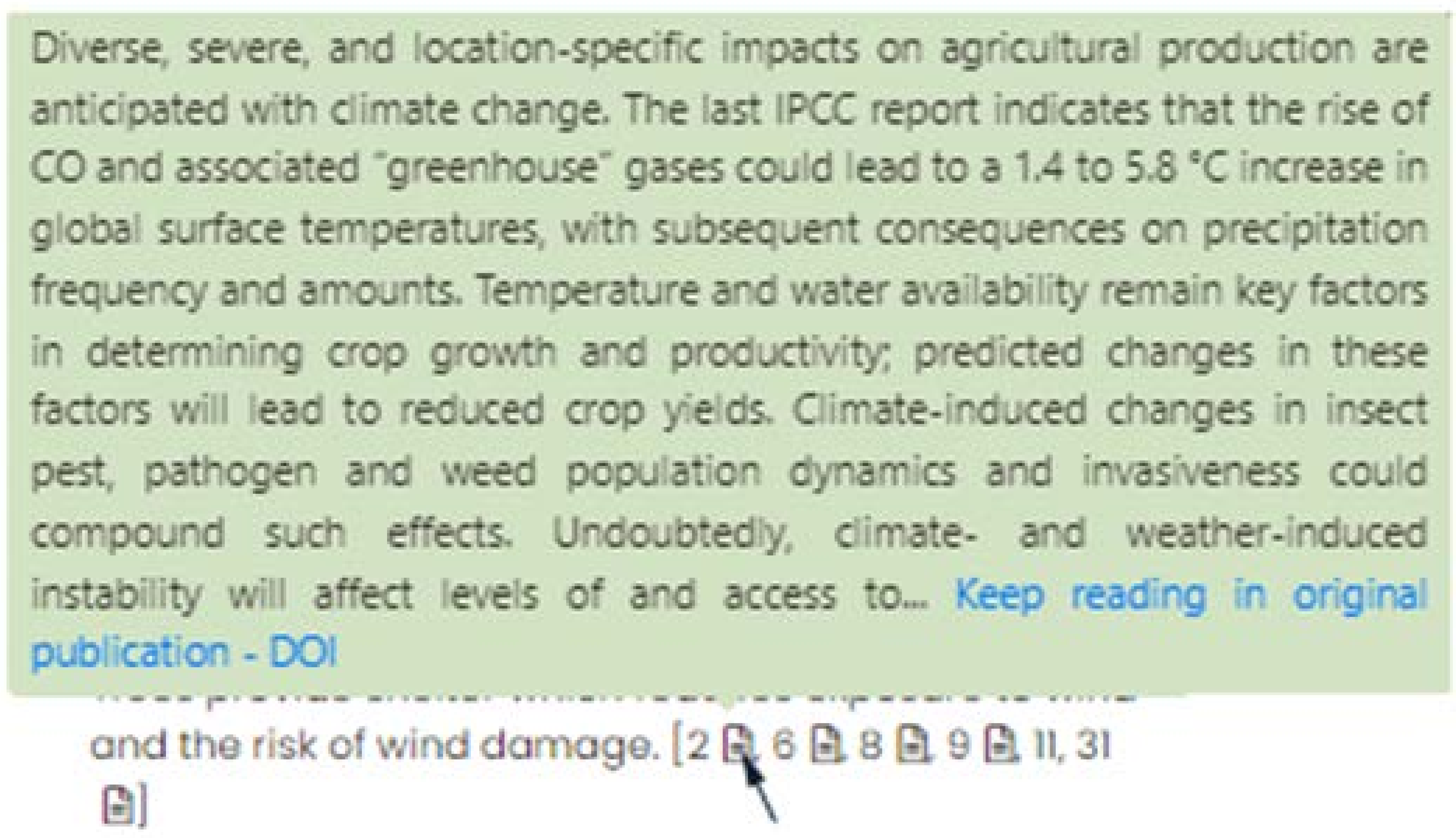
A list of the **agroforestry types** that were identified by experts to be **more resilient than the baseline** for the selected region and climate impact driver is then presented. For each type, the **resilience level** for all impact drivers is shown on a **radar diagram** (top left corner), plus a list of the **key mechanisms listed by the experts**, supported by **scientific references, caveats** and **trade-offs**.



Hovering over titles and themes highlights their descriptions.



Clicking on the publication symbol opens an **excerpt of the abstract**, with a link for further reading in the **source publication with a DOI**.



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For each resilient land use, there is a list of case studies with **real-life examples** of agroforestry to provide inspiration. Each has a small description, details on each of the system components, and links for further exploration.

Hestbjerg Økologi *case study*

Land use	Agrosilvopastoral	Denmark	1000 ha
Climate region	Northern Europe	https://hestbjerg.dk/poppelgris-fra-hestbjerg/	
		https://hestbjerg.dk/wp-content/uploads/2017/08/Hestbjerg_folder_en.pdf	

Description	The farm includes sows and piglets (outdoor) and finishers (organic indoor stables with access to outdoor concrete runs) approximately 1100 sows. The trees are (mainly) implemented on the areas 'grazed' by the lactating sows. The pork is (mainly) sold as 'Poppelgris fra Hestbjerg' (Poplarpig from Hestbjerg): https://hestbjerg.dk/poppelgris-fra-hestbjerg/
Tree	Mainly poplar, but depending on farm site, also Sitka spruce, Cherry plum, Aronia, Hazel, Wild apple. The trees are planted in rows, and located at the end of each individual sow paddock. Tree density varies between locations (1500-1800 trees per hectare). For example, at one farm site, plants per hectare: Poplar = 1250, Cherry plum, Aronia, Hazel, Wild apple, each = 83. The first poplar trees established in 2011 while the latest (above mentioned example) was established in 2021.
Crops	Pasture (grass clover) and cereals (e.g. barley undersown with grass clover) in a two year crop rotation
Livestock	The farm includes sows and piglets (outdoor) and finishers (organic indoor stables with access to outdoor concrete runs). The trees are (mainly) implemented on the areas 'grazed' by the lactating sows. The pork is (mainly) sold as 'Poppelgris fra Hestbjerg' (Poplarpig from Hestbjerg)

BOX: The science behind the LUCIM

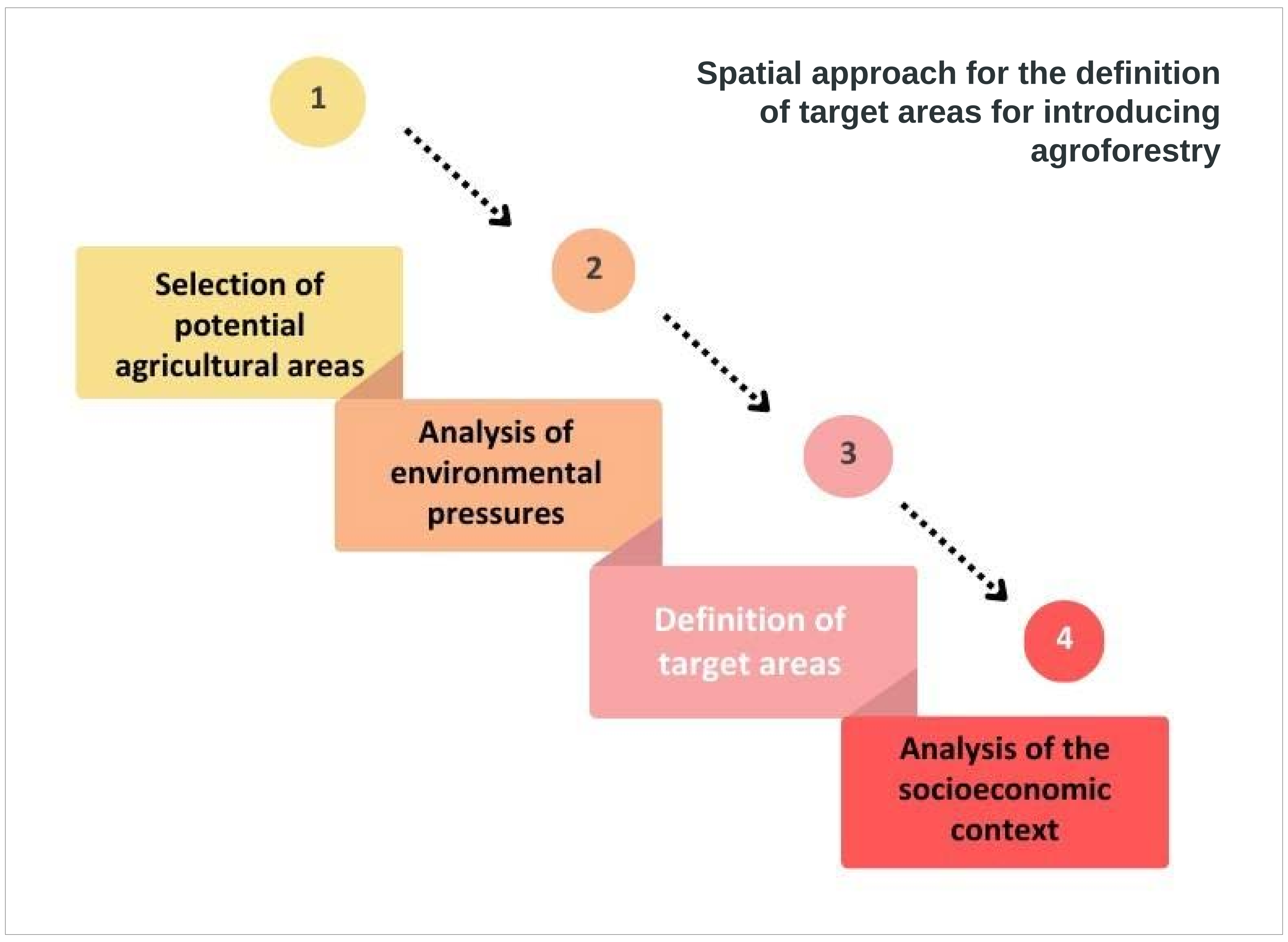
The selection of target areas used a spatial approach which consisted of four steps (see figure below):

(1) selection of suitable potential areas from the total agricultural area in Europe, excluding nature conservation sites and agroforestry areas identified in the land use/land cover cartography,

(2) analysis of 14 environmental indicators to map risks related to soils, biodiversity, water and climate change. in the potential areas,

(3) definition of target areas where there were seven or more accumulated environmental risks;

(4) analysis of the socio-economic context, based on six social and economic indicators related to economy, training and willingness of farmers to change and demography.



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agromix

Transforming landscapes

The development of the step-by-step approach to identify agroforestry types that increase resilience to climate impact drivers used an iterative expert-knowledge-based approach called the 'Delphi' method. 60 experts from across Europe were involved in evaluating the resilience to climate change of different agroforestry types in comparison with monocultures of temporary crops or trees. In addition to providing a score of the level of resilience (shown in the radar diagram in the LUCIM), experts proposed the mechanisms and characteristics of the agroforestry types that determined the resilience level, as well as key caveats and trade-offs for the system. Using a qualitative analysis approach called *thematic content analysis*, these mechanisms, characteristics, caveats and trade-offs were grouped into overarching themes; in the LUCIM, these are listed for each agroforestry type, compared with a specific baseline system. Scientific references that provide evidence on these mechanisms were also proposed by the experts and have been linked to the themes. To illustrate the generic agroforestry type descriptions with real-world examples, case studies of agroforestry farms across Europe were sourced from previous and existing EU projects and resources, as well as from the experts.

References:
Tomás, A., Smith, J., Gabourel, A., Lavado Contador, J. F., Schnabel, S., & Palma, J. (2024, May 29). The AGROMIX Land Use Change Interactive Map at a European Scale. 7th European Agroforestry Conference, Brno, CZ. AGROMIX/EURAF. https://doi.org/10.5281/zenodo.12820330

Deliverable report. Reserved DOI: 10.5281/zenodo.11085408

Contact:
josmith@mvarc.eu

Authors:
Jo Smith, Ana Tomás and João Palma - MVARC, Mértola, Portugal
Susanne Schnabel, J. Francisco Lavado Contador, Anthony Gabourel Landaverde – INTERRA, University of Extremadura, Cáceres, Spain

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