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agromix

D3.5: Draft framework to identify European target regions for Mixed Farming and Agroforestry

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Deliverable 3.5	**Draft framework to identify European target regions for Mixed Farming and Agroforestry**
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[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified

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Table of Contents

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1. Executive Summary

This report presents the first deliverable of Task 3.3 which builds on the other WP3 tasks focusing on plot and farm-level impacts by exploring land use/resilience strategies at the landscape level. This Deliverable 3.5 presents the draft Framework and transdisciplinary approach to upscaling, which combines spatial modelling and expert knowledge, that this task follows. This work contributes to the project objectives by providing optimised and broader spatial contexts where agroforestry (AF) or mixed farming (MF) could be implemented to increase the environmental resilience of agricultural systems and provide effective climate change mitigation and adaptation strategies.

A spatial approach (Sub-task 3.3.1) to up-scaling is used to identify target areas in Europe where resilient and climate-smart MF/AF systems should have high priority for introduction, while a non-spatial approach (Sub-task 3.3.2) is used to develop future scenarios of land use/resilience strategies where different models of land use change will be evaluated as pathways towards increased resilience to climate change.

In Sub-task 3.3.1, the selection of target areas for introducing MF/AF is based on a spatial approach which consists of five steps: (1) baseline mapping of suitable potential areas from the total agricultural area in Europe, excluding nature conservation sites and existing MF/AF areas (2) analysis of environmental risks in the potential areas, (3) identification of target areas, (4) integrated analysis of the socio-economic context, and, finally (5) evaluation of small woody features in the target areas.

1. The Land-Use based Integrated Sustainability Assessment (LUISA) base map was used to select the target areas to introduce agroforestry and mixed farming by estimating the total agricultural area for the EU-27, the United Kingdom and Switzerland, resulting in 1,722,866 km^2. Additionally, the Natura 2000 Network, RAMSAR sites maps and, for Switzerland, the Emerald Network of Areas of Special Conservation Interest, were used to identify the areas of nature conservation while MF/AF classes were identified on the LUISA base map with a combined total area of 249,472 km^2. Once nature conservation areas and mixed farming and agroforestry land cover classes were subtracted from the total agricultural area, the potential areas for introducing MF/AF systems amounted to a total of 1,537,326 km^2. According to the distribution of potential areas by country, France (15.6%), Spain (12.1%), Germany (10.9%), Poland (9.6%) and the United Kingdom (8.9%) contained most of the total agricultural potential area, comprising together 57% of the total surface.

2. The analysis of environmental risks in the potential areas identifies 11 environmental indicators as risks in relation to soils (soil erosion by water and wind, loss of soil organic matter), biodiversity (potential threats to soil biodiversity, pest control index, pollinator potential), water (irrigated areas, nitrogen surplus), and climate change (predictions for annual mean temperature, aridity index, drought frequency, heavy precipitation). Datasets of these indicators were gathered from cartographic products developed at European or national scales and available as public data or on demand. In order to evaluate the effects of those risks, threshold values were defined for each indicator, identifying the limits above or below which sustainability is compromised in potential areas.

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3. Target areas are identified by combining the environmental indicators to produce heat maps that highlight the intensity of environmental risks and identify areas that have a high concentration of risks to determine priority areas to introduce MF/AF. An analysis will be performed by land use/land cover category to identify endangered categories.

4. Analysis of the socio-economic context aims to characterise areas with different needs of policy support. A total of six social and economic indicators related to demography (ratio of young to elderly farmers, degree of urbanisation), education (training of farm managers, number of organic farming holdings) and economy (economic size and unemployment rate) will be analysed in NUTS 2 regions of the EU27, Switzerland and United Kingdom. These indicators are used to characterize the social and economic conditions, using the data available in Eurostat for the European regions.

5. Evaluation of small woody features in the target areas. Once the target areas are identified, the woody landscape features described in WP1 (Schnabel et al., 2022), using the Land Use/Cover Area frame Survey (LUCAS) and High-Resolution Small Woody Features dataset from Copernicus, will be used to detect these features allowing to fine-tune the selection of target areas.

While target regions for introducing MF/AF systems to increase resilience are identified spatially in Sub-task 3.3.1, the transition towards a particular land use system occurs at the plot/farm decision level. In Sub-task 3.3.2, the focus is on identifying different models of land use change to evaluate pathways towards increased resilience to climate change. Therefore, this sub-task focuses on delivering a suite of problem-solution based land use change models to deliver a close-to-practice ensemble for farmers to use. In the context of AGROMIX, the 'problem' we are addressing is the impact of climate change on agricultural and forestry systems, and the 'solution' is a change in land-use towards a more resilient system. The land-use models we focus on are mixed farming and agroforestry, building on the AGROMIX classification, and demonstrated with real-world examples using case studies captured in the AGROMIX project as well as from other sources including other EU projects, EIP Focus Groups, European agroforestry associations, and from expert knowledge. As there are significant research and evidence gaps in knowledge concerning the resilience of mixed farming and agroforestry land use models to climate change, an iterative expert knowledge-based Delphi method will be used. Delphi is an effective method of facilitating a group of individuals as a whole to deal with a complex problem and reach consensus through an iterative feedback process.

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This draft framework contributes to reaching the goal of the AGROMIX project of driving the transition to a resilient and efficient land use in Europe through the development of mixed farming and agroforestry in the following ways:

- First, by developing a spatial approach that identifies and maps target areas for implementing agroforestry or mixed farming. This approach prioritises areas where introducing AF/MF can potentially contribute to increasing the resilience of the current agricultural systems, through mitigation of environmental pressures such as soil erosion, biodiversity loss and water shortages, combined with predicted climate change impacts.
- Second, by considering the socio-economic context in which the transition of land use needs to occur. For successful implementation of more complex agroecological systems such as AF/MF, targeted policy support is needed that is appropriate to the socio-economic context of each region.
- Third, by identifying the most resilient and appropriate types of AF/MF for the target regions. AF/MF systems are not 'one size fits all' approaches, and a better understanding of the particular characteristics, properties and potential trade-offs of these varied land use models provides policy makers, land managers and farmers with the tools they need to make informed decisions regarding a transition towards a more resilient agricultural system for Europe.
- Fourth, by combining the outputs of the spatial and non-spatial approaches into a user-friendly interactive map (Deliverable 3.3, due April 2024). Users of the interactive map will be able to explore the environmental and climate change pressures of their chosen region, to identify the target areas where implementing AF/MF may increase resilience, as well as gain a better understanding of the socio-economic context of that region that may impact policy decisions. Then they will be able to review different types of agroforestry and mixed farming land use models that can be implemented in these regions, along with consideration of potential trade-offs, and illustrated with real-life case studies.

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2. Expected impact

The AGROMIX research project (1 November 2020 – 31 October 2024), funded by the European Commission, is a research and innovation project that focuses on the transition towards resilient farming, efficient land use, and sustainable agricultural value chains in Europe. AGROMIX aims to deliver participatory research looking specifically at mixed farming (MF) and agroforestry (AF) systems as practical agroecological solutions for farm and land management and related value chains (**www.agromixproject.eu**).

This report presents the first Deliverable of AGROMIX's Work Package 3 (WP3) Task 3.3 that aims to develop future scenarios of land use/resilience strategies. The objective of WP3 is to determine the effect of transition scenarios for increased agroforestry (AF) and mixed farming (MF) on climate resilience at plot-farm- and landscape levels. Task 3.3 builds on the other WP3 tasks that are focusing on plot and farm-level impacts to explore land use/resilience strategies at the landscape level. The consequences of a wide application of climate resilient MF/AF systems at a regional, and possibly European scale, will be evaluated and made available to policy makers (WP6). At the same time, this task will contribute to the project objectives by providing optimised and broader spatial contexts where agroforestry (AF) or mixed farming (MF) could be implemented to increase the environmental resilience of agricultural systems and provide effective climate change mitigation and adaptation strategies. Therefore, this task and associated deliverables will primarily help to achieve the project's specific objective SO4 'To identify and model key transition scenarios and trade-offs in climate smart land use systems, value chains and infrastructure to inform policy options.'

The research is expected to impact farmers and land managers, by first highlighting areas of climate and environmental risk where an agroforestry or mixed farming approach could be implemented and then by identifying a range of AF/MF land use models that could increase resilience to climate change, illustrated with real-life examples. For policy makers, the outcomes of the spatial modelling and land use change pathway development could be used to inform policy development to support the uptake of AF/MF in priority areas and address any potential social and economic factors that may be barriers to, or conversely, opportunities for implementation (e.g. labour shortages). For researchers, in addition to the transdisciplinary methodological development, and associated data, mapping and literature review, the conclusions of the research can help inform future research priorities with regards evaluation/targeting of AF/MF approaches for increasing climate change resilience.

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3. Introduction

3.1. Resilience of Agroforestry and Mixed Farming systems

In line with the aim of the AGROMIX project, we focus on the resilience of farm and land management to climate change. The AGROMIX project builds on a definition by Meuwissen *et al.* (2019) to identify the resilience of a farming system to climate change as the "ability to ensure the provision of the desirable functions of the farming system to climate shocks and stresses". Meuwissen et al (2019) recognised three different forms of resilience (Figure 1); robustness (being able to absorb or resist shocks and stresses), adaptability (being able to adjust to the changes) and transformability (being able to move the existing system to a stronger one). The form of resilience of a particular system will partly depend on the intensity of the shock or stress.

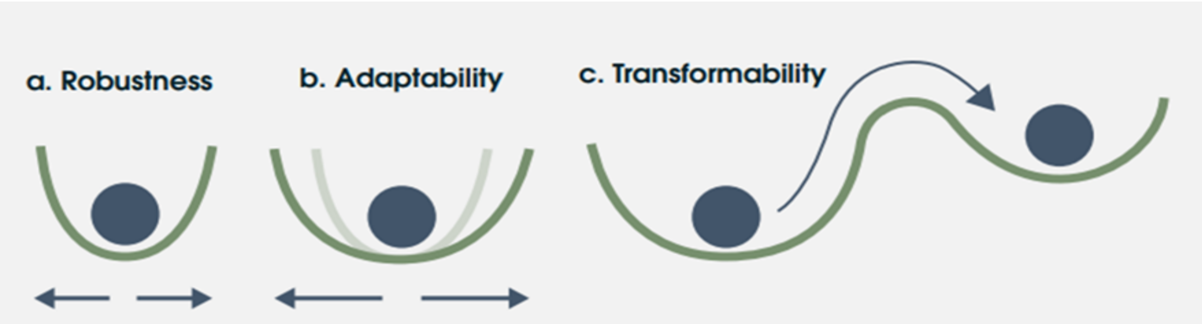

Figure 1. Three forms of resilience – robustness, adaptability and transformability – illustrated schematically as a ball (the state of a farm) in a stability landscape (from D3.7)

The IPCC identifies agroecological systems, including agroforestry, as highly effective adaptation options that enhance resilience to climate change (Bednar-Friedl et al., 2022). In this task, the resilience concept is integrated into a spatial approach which focuses on mapping environmental pressures where AF/MF have been shown to mitigate impacts and thus increase resilience e.g. by supporting better soil structure and higher soil organic matter levels (Young, 1985) to reduce soil erosion, by increasing water infiltration and reducing surface water runoff and consequently reduce flood risks (Seobi et al., 2005; Anderson et al., 2009) and by supporting higher biodiversity, agroforestry systems to increase resilience against impacts of climate change on pollination services and increased pest and disease risks (Jose, Gillespie and Pallardy, 2004; Staton et al., 2019, 2021; Varah et al., 2020).
The resilience concept is also central to the non-spatial component of this task, whereby the resilience of different AF and MF land use models to climate change is evaluated, and the drivers underpinning their resilience identified.

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3.2. Task Overview

Task 3.3 is divided into two sub-tasks. The first, Sub-task 3.3.1, employs a spatial approach to up-scaling to identify target areas in Europe where resilient and climate-smart mixed farming (MF) and agroforestry (AF) systems should have high priority for introduction. Target areas are determined for the European Union, UK and Switzerland based on spatial analysis of the main pressures suffered in agricultural areas, including environmental risks, climate change projections, as well as socio-economic conditions. The second Sub-task (3.3.2) uses a non-spatial approach to developing future scenarios of land use/resilience strategies. Different models of land use change will be developed to evaluate pathways towards increased resilience to climate change.

This Deliverable 3.5 presents the draft Framework and associated methodologies that the two approaches to upscaling will follow. The outcome of the subsequent research will be the identification of European target regions for mixed farming and agroforestry. This will be presented in Deliverable 3.3, due in April 2024, in the form of a multilingual interactive European map with target regions for MF/AF systems and proposed land use models per region, that will be made available on the project website.

3.3. Framework approach

The upscaling combines spatial modelling (Sub-task 3.3.1) and a transdisciplinary approach to co-produce knowledge (Sub-task 3.3.2). Upscaling is understood here as extrapolating information, data or knowledge from a finer spatial scale a coarser scale, in our case regional or landscape scales. This framework builds on the conceptual approach developed by Kay et al. (2019) that was used to identify the Priority Area in European farmland where the implementation of agroforestry could address multiple environmental pressures. Kay et al. (2019) used spatial modelling to first identify 'Focus Areas' (i.e., European agricultural land excluding nature conservation areas, High Nature Value Farmland and existing agroforestry land) as potential areas suitable for implementation of agroforestry. In a second step, environmental pressure indicators were spatially aggregated and combined into a 'Pressure Areas' map. A final step produced a heatmap of environmental pressures where the 10% of the area with the highest number of environmental pressures were defined as the Priority Area for implementation of agroforestry. Alongside this spatial modelling, agroforestry experts across Europe were asked to propose and describe potential agroforestry practices for the Priority Area. A literature review extracted data on carbon storage potential of the proposed agroforestry systems and these values were then used for upscaling to the Priority Area to estimate carbon sequestration potential of implementing agroforestry (Kay et al. 2019).

To achieve the AGROMIX project aims, Task 3.3 develops this conceptual framework further by incorporating climate change projection for various climate variables , as well as considering the socio-economic conditions. The aim is to define areas in the EU, UK and Switzerland where mixed agricultural systems or agroforestry should have a high added value, and adoption is highly recommended. Sub-task 3.3.1 will carry out spatial modelling to; first, identify suitable potential areas, second, map a range of environmental and climate change variables to identify areas of high pressure, and finally to define and then identify target areas, for implementation of agroforestry or mixed farming (Figure 2). In a next step, the socio-economic context of the target areas is analysed, with the aim of differentiating areas with different needs of policy support. Finally, woody landscape features are considered using a density map

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allowing to fine-tune the selection of target areas. Sub-task 3.3.2 will complement the first sub-task by identifying appropriate agroforestry and mixed farming models for the target areas. It will use a non-spatial approach that combines expert knowledge and literature review to first identify the climate change resilience potential of agroforestry and mixed farming systems before developing and delivering a suite of problems-solution based land-use-change models (Figure 2). The outcomes of both sub-tasks will be illustrated in an on-line interactive European map that enables users to view European target regions for mixed farming and agroforestry and proposed prototypes that increase climate change resilience (Section 6, Deliverable 3.3).

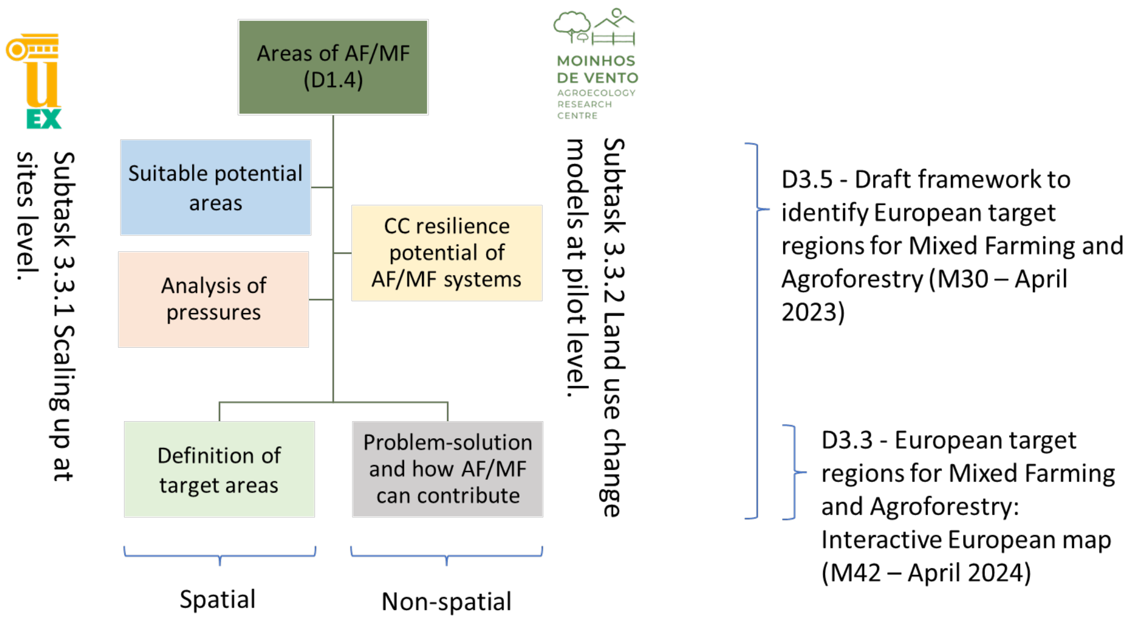

Figure 2. Framework for the development of future land-use/resilience strategies (Task 3.3)

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3.4. Supporting the transition to a resilient and efficient land use in Europe

This draft framework contributes to reaching the goal of the AGROMIX project of driving the transition to a resilient and efficient land use in Europe through the development of mixed farming and agroforestry in the following ways:

- First, by developing a **spatial approach** that identifies and maps target areas for implementing agroforestry or mixed farming. This approach prioritises areas where introducing AF/MF can potentially contribute to increasing the resilience of the current agricultural systems, through mitigation of environmental pressures such as soil erosion, biodiversity loss and water shortages, combined with predicted climate change impacts.
- Second, by considering the **socio-economic context** in which the transition of land use needs to occur. For successful implementation of more complex agroecological systems such as AF/MF, targeted policy support is needed, that is appropriate to the socio-economic context of each region.
- Third, by identifying the most **resilient and appropriate types of AF/MF for the target regions**. AF/MF are not 'one size fits all' approaches, and a better understanding of the particular characteristics, properties and potential trade-offs of these varied land use models provides policy makers, land managers and farmers with the tools they need to make informed decisions regarding a transition towards a more resilient agricultural system for Europe.
- Fourth, by combining the outputs of the spatial and non-spatial approaches into a **user-friendly interactive map (**Deliverable 3.3, due April 2024). Users of the interactive map will be able to explore the environmental and climate change pressures of their chosen region, to identify the target areas where implementing AF/MF may increase resilience, as well as gain a better understanding of the socio-economic context of that region that may impact policy decisions. Then they will be able to review different types of agroforestry and mixed farming land use models that can be implemented in these regions, along with consideration of potential trade-offs, and illustrated with real-life case studies.

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4. Scaling up at sites level

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4.1. Introduction

This section presents the methodology proposed for Sub-task 3.3.1 dedicated to the identification of target areas in Europe where resilient and climate-smart mixed farming or agroforestry systems would have high priority for introduction. It includes the European Union member states (EU27), United Kingdom (UK) and Switzerland (CH). Necessary cartography and associated databases with the main characteristics of MF/AF over Europe were provided by WP1 task 4. Data mining and geo-spatial modelling is being used to identify those target areas. The methodological framework applied is based on an adaptation of the one used by Kay et al. (2019) for agroforestry systems. The principal steps used by these authors to define priority areas, i.e. where agroforestry could increase the provision of ecosystem services, consisted in the determination of (i) focus areas, (ii) pressure areas and (iii) priority areas. "Focus areas" were defined as European agricultural land excluding the areas of high nature value, such as Natura 2000, High Nature Value Farmland and the existing agroforestry areas. In the next step, the susceptibility of these "focus areas" to nine environmental pressures was determined and evaluated using predefined thresholds and added together to define "pressure areas". Finally, "priority areas" were those areas where the number of pressures exceeded a certain limit depending on whether it is arable land or pastureland.

The aim of our analysis is to define target areas where the introduction of mixed farming or agroforestry would provide environmental benefits and also be more resilient to climate change. The selection of these target areas is based on a spatial approach which consists of five steps (Figure 3): (1) selection of suitable potential areas from the total agricultural area in Europe, excluding nature conservation sites and MF/AF areas identified in the land use/land cover cartography, (2) analysis of environmental risks in the potential areas, (3) definition of target areas, (4) analysis of the socio-economic context, and, finally, (5) evaluation of small woody features in the target areas.

Although the basic approach follows the one of Kay et al. (2019) our study varies in several ways. Firstly, we do not only consider agroforestry as an alternative agricultural system but also mixed farming. Secondly, potential areas are agricultural areas that exclude those areas that are either protected nature reserves or are already MF/AF systems. There are basically two options to determine the spatial distribution of MF/AF areas: land use maps such as CORINE or LUISA and the LUCAS database. Both types of spatial datasets present disadvantages. The land use maps do not include MF as a category and the category AF does not include all agroforestry areas. On the other hand, the LUCAS database does not allow identification of most areas with MF, except for the combination of temporary cropland with grazing livestock (Schnabel et al., 2022). Furthermore, LUCAS data are point data and its extrapolation to spatially explicit surface areas is difficult and impossible where AF point density is low. Contrary, land use maps are clearly defined polygons. Therefore, it was decided to use those in this study. Chapter 4.1 describes in more detail its application for the definition of potential areas.

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Thirdly, regarding suitable potential areas, Kay et al. (2019) differentiated between arable areas and pastureland. In our case, we divide arable areas into cropland and permanent crops because the starting conditions for transformation into either MF or AF, are different. In this sense, areas with permanent crops already include the trees, and their transformation to AF is hence more probable. Grazed grasslands already include livestock, and the transformation into cropland to create a MF system may be less feasible than the conversion to AF with the introduction of trees. Finally, agricultural land, such as cropland or grazed grasslands, may include woody vegetation (shrubs and trees), such as hedgerows, windbreaks, riparian vegetation, and these are widespread in many parts of Europe (Mosquera-Losada et al., 2018). Several authors consider these systems as a type of AF (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. Therefore, once the analysis of environmental pressures of the potential areas has been carried out, the target areas have been defined and the socio-economic context has been analysed, a separate analysis regarding the existence of woody elements will be undertaken. The aim of this additional analysis is to identify whether the environmental risks in these areas are different from agricultural land without woody features. Furthermore, agricultural land with high risks and without woody elements are considered target areas with higher priority for introducing MF or AF (Figure 3).

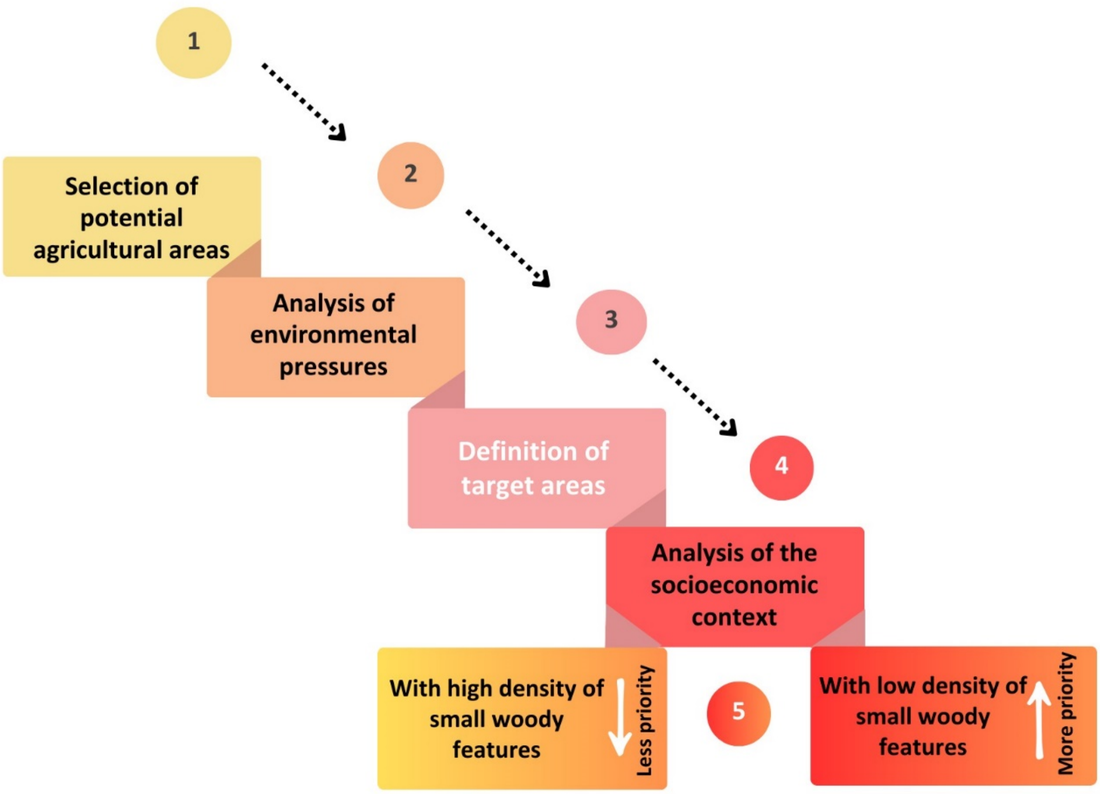

Figure 3. Spatial approach for the definition of target areas for introducing MF/AF.

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4.2. Selection of suitable potential areas

Suitable potential areas were estimated from the total agricultural land of the European Union (EU) 27 Member States, the United Kingdom (UK) and Switzerland (CH). Croplands, permanent crops, and pastures were accounted for to estimate the total agricultural area (Figure 4), which are land cover/land use classes spatially distributed in the selected countries.

It should be noted that the outermost regions of the EU27, such as Guadeloupe, French Guiana, Réunion, Martinique, Mayotte and Saint-Martin (France); the Azores and Madeira (Portugal), and the Canary Islands (Spain), were not included for the estimation of the total agricultural area, as most of the datasets used for the analysis of environmental pressures excluded these regions due to their geographical remoteness.

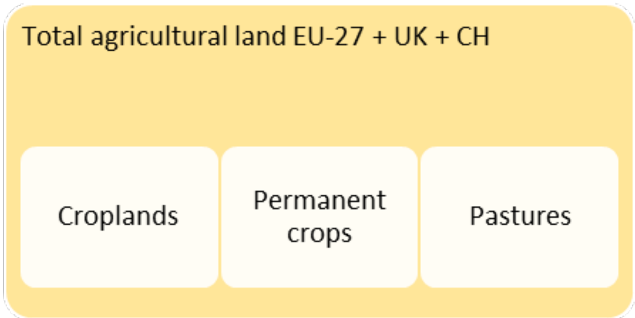

Figure 4. Selection of suitable potential areas in the EU, United Kingdom and Switzerland from the total agricultural land, including croplands, permanent crops and pastures.

4.2.1. Estimation of the total agricultural area

The Land-Use based Integrated Sustainability Assessment (LUISA) base map from 2018 (Batista and Pigaiani, 2021) was used to estimate the total agricultural area, considering the land use classes from

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Table 1. 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.

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Table 1. Distribution of land use/cover classes for the estimation of the total agricultural area in the EU, UK and Switzerland in 2018.

LUISA Code	Label	Cropland	Permanent crops	Pasture	Total area (km^2)	Total area (%)
2110	Non irrigated arable land				1,018,692	59.1
2120	Permanently irrigated land				39,860	2.3
2130	Rice fields				6,370	0.4
2210	Vineyards				34,385	2.0
2220	Fruit trees and berry plantations				25,527	1.5
2230	Olive groves				45,277	2.6
2310	Pastures				447,854	26.0
3210	Natural grassland				104,901	6.1
				Total area	**1,722,866**	**100.0**

The total agricultural area for the EU-27, the United Kingdom and Switzerland was 1,722,866 km^2. Cropland classes included non-irrigated arable land (59.1% of the total agricultural area), permanently irrigated arable land (2.3%) and rice fields (0.4%). Permanent crops included vineyards (2.0%), fruit trees and berry plantations (1.5%) and olive groves (2.6%). The third group consisted of pastures (26%) and natural grasslands (6.1%).

The most frequent classes were non-irrigated arable land, pastures, and natural grasslands, which, in combination, represented more than 90% of the total agricultural area. Concerning the groups of analysis, croplands represented (62%), pastures (32%) and permanent crops 6% (Figure 5).

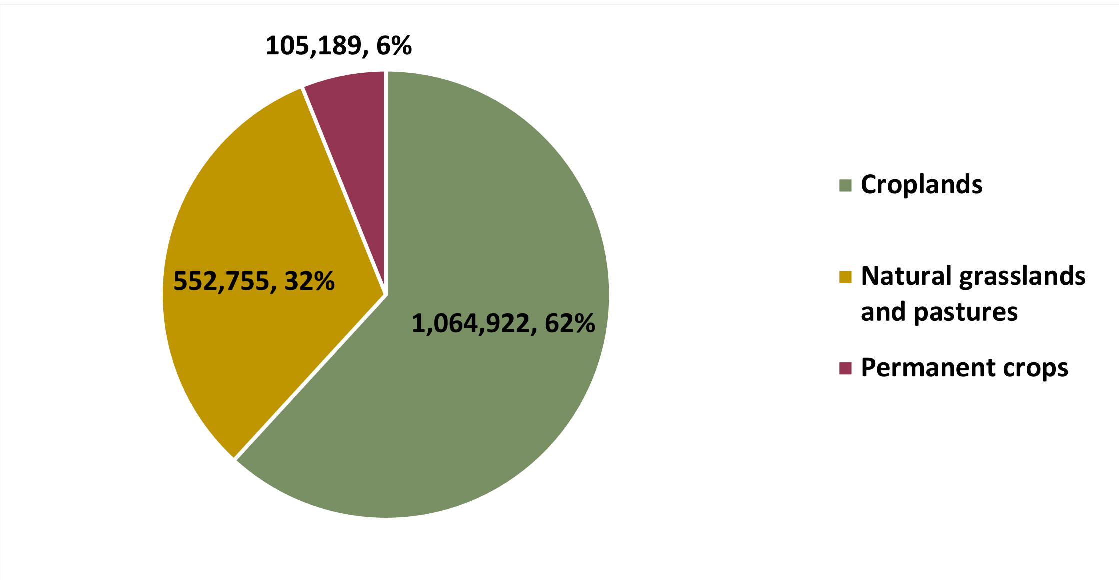

Figure 5. Percentage (%) and total agricultural area (km^2) for croplands, permanent crops, natural grasslands and pastures in the EU, UK and Switzerland.

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4.2.2. Identification of nature conservation sites excluded from potential areas.

Nature conservation areas are subject to specific rules and regulations due to legal agreements and conventions aimed at preserving biodiversity and natural habitats. Although land use changes may be allowed in some cases, it is not practical to consider regional regulations separately for all of Europe. Therefore, these areas were excluded from the estimated total agricultural land and were considered unsuitable for introducing MF/AF practices. The Natura 2000 Network ((EEA, 2022b) and the RAMSAR sites maps (SISR, 2022) were used to determine these areas. In Switzerland, protected sites were identified using the Emerald Network of Areas of Special Conservation Interest (FOEN, 2018) (as shown in Table 2).

Table 2. Base maps used for the selection of nature conservation areas in Europe.

Cartography	Data type	Source	Coverage	Resolution
Natura 2000 Network	Natural protected areas	(EEA, 2022b)	EU 27, UK	100 m
Emerald network	Natural protected areas	(FOEN, 2018)	Switzerland	100 m
Ramsar sites	Protected wetlands	(SISR, 2022)	All Europe	100 m

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4.2.3. Identification and distribution of MF/AF classes from the LUISA Base map not considered as potential areas

Regarding the identification of areas with mixed farming and agroforestry using the LUISA base map, those can only be considered approximations because no mixed farming category exists and not all AF areas in Europe are represented. It was decided to include the following land uses as representative of MF/AF systems (Table 3): *Annual crops associated with permanent crops* (silvoarable system), *Complex cultivation patterns* (combination of annual crops, pasture and/or permanent crops, including kitchen gardens, which are considered AF), *Land principally occupied by agriculture, with significant areas of natural vegetation (*mosaics of agricultural land combined with natural and semi-natural areas*)*, and *Agroforestry areas* (most of them *dehesas* and *montados* mainly located in the Southwest of the Iberian Peninsula, i.e. Portugal and Spain). It must be taken in mind that these classes do not correspond to the total MF/AF surface in Europe, only representing the areas that can be obtained from the LUISA map. These areas are called MF/AF in order to make it clear that they refer to areas characterized by heterogeneous land uses and land covers which can be considered MF/AF systems.

Table 3. Mixed farming and agroforestry related classes identified in the land cover map developed in the Land-Use based Integrated Sustainability Assessment modelling platform (LUISA) for the year 2018. These land cover classes only represented a proportion of the total agricultural area and were excluded from the suitable potential area to introduce mixed farming and agroforestry systems, as those are already characterized by different combinations of trees, permanent and temporary crops, or pastures.

LUISA Code	Label	Total area (km^2)	Total area (%)
2410	Annual crops associated with permanent crops	3,901	1.6
2420	Complex cultivation patterns (kitchen gardens)	113,036	45.3
2430	Land principally occupied by agriculture	102,424	41.1
2440	Agroforestry areas	30,110	12.1
	Total area	249,472	100.0

While these classes were not considered for the estimation of the suitable potential areas in Europe, they will be used for further analyses. MF/AF classes together represented a total area of 250,185 km^2, being the most prevalent class complex cultivation patterns (45.2%) and land principally occupied by agriculture (41.2%) (Figure 6). Agroforestry areas represented 12% of the land, while annual crops associated with permanent crops were only 1.2% of the area.

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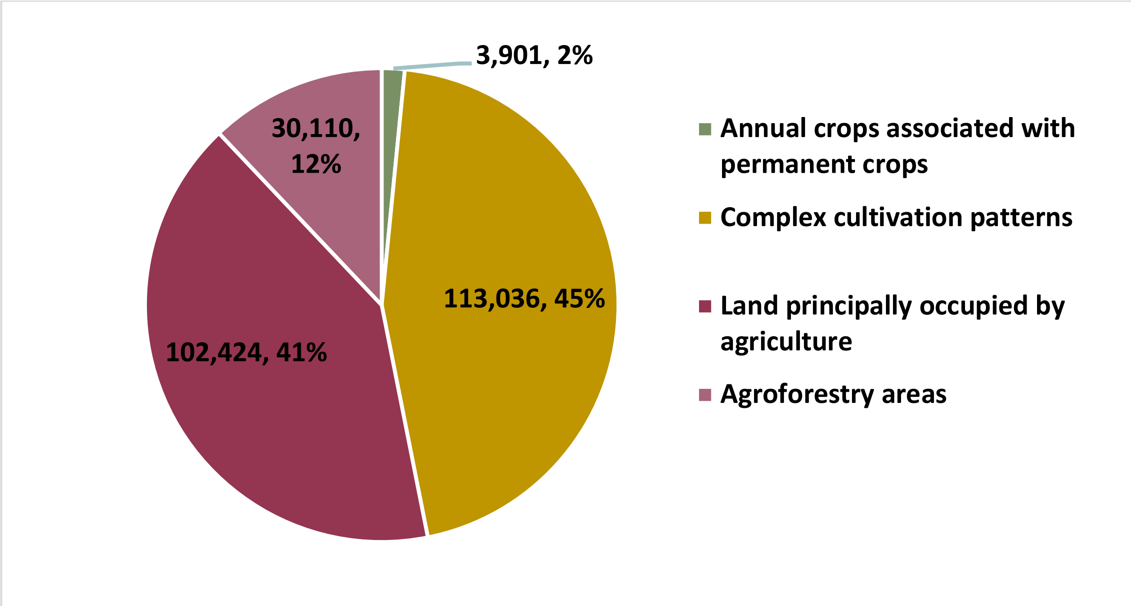

Figure 6. Percentage (%) and total surface (km^2) of MF/AF classes observed in the LUISA base map of land use/cover for the EU, UK and Switzerland.

4.2.4. Estimation of the suitable potential areas

Once nature conservation sites and MF/AF classes were subtracted from the total agricultural area, potential areas for introducing MF/AF systems amounted to a total of **1,537,326 km^2** (Figure 7)**.** According to the distribution of potential areas by country, Denmark (62%), Ireland (56%), United Kingdom (56%), Hungary (53%) and Netherlands (49%) had the largest share of the potential area in proportion to the surface area of the country (Figure 8). However, France (15.6%), Spain (12.1%), Germany (10.9%), Poland (9.6%) and the United Kingdom (8.9%) contained the largest share of potential areas (57%) with respect to the total agricultural potential area (Table 4).

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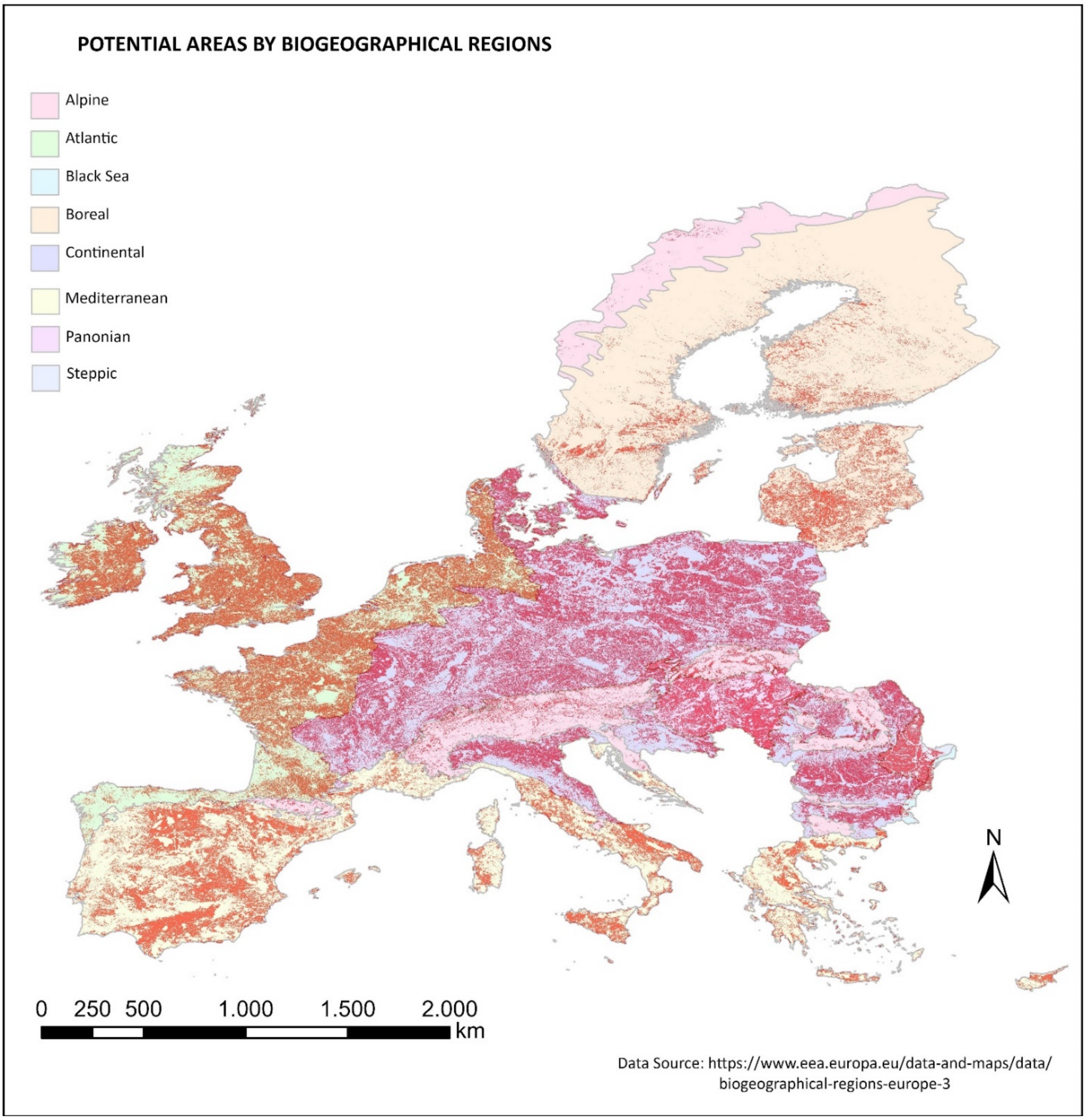

Figure 7. Suitable potential areas for introducing MF/AF in the EU, UK and Switzerland by biogeographical regions.

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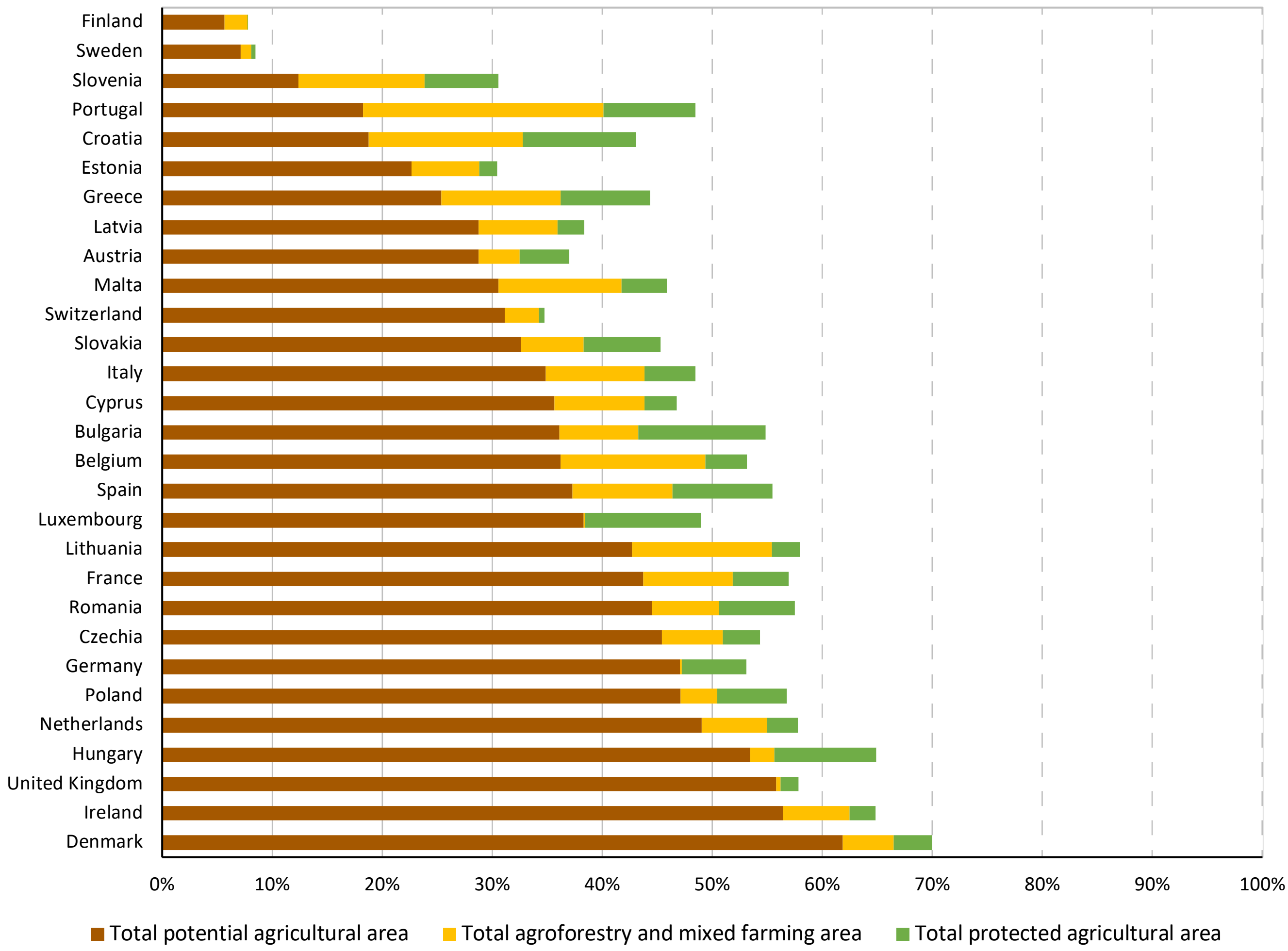

Figure 8. Suitable potential agricultural area, mixed farming and agroforestry systems area and protected agricultural area as percentage of the total country surface in the EU, UK and Switzerland.

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Table 4. Total country surface, potential agricultural area for introducing mixed farming (MF) and agroforestry systems (AF), current MF/AF related area and protected agricultural area by country (CH: Switzerland, UK: United Kingdom).

Country	Country area (km^2)	Potential agricultural area (km^2)	MF/AF area(km^2)	Protected agricultural area (km^2)
Austria	83945	24138	3110	3835
Belgium	30666	11103	4032	1162
Bulgaria	110994	40062	7976	12866
Croatia	56516	10612	7896	5836
Cyprus	9257	3301	759	268
Czechia	78873	35817	4390	2655
Denmark	43171	26700	1996	1509
Estonia	45345	10266	2805	741
Finland	337523	19195	6976	284
France	548942	240005	44703	27789
Germany	357661	168304	523	20986
Greece	131759	33393	14287	10750
Hungary	93009	49696	2050	8596
Ireland	69940	39448	4239	1676
Italy	300650	104769	27001	14000
Latvia	64587	18561	4660	1569
Lithuania	64897	27731	8239	1651
Luxembourg	2596	995	2	274
Malta	314	96	35	13
Netherlands	37380	18335	2213	1042
Poland	311941	146907	10387	19784
Portugal	88786	16195	19395	7455
Romania	238368	106110	14542	16456
Slovakia	49024	15981	2784	3446
Slovenia	20272	2511	2323	1365
Spain	498556	185759	45569	45226
Sweden	449657	32053	4328	1727
Switzerland	41286	12849	1284	203
United Kingdom	244545	136434	966	4031
Total EU27, CH, UK	**4410460**	**1537326**	**249472**	**217197**

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4.3. Analysis of environmental risks

A total of 11 environmental indicators were used to determine risks (

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Table 5) to soils, biodiversity, water, and climate change. Datasets of these indicators were gathered from cartographic products developed at European or national scales and available as public data or on demand. In order to evaluate the effects of those risks, threshold values were defined for each indicator, identifying the limits above or below which sustainability is compromised in potential areas.

4.3.1. Soil related risks

The European Union Soil Observatory reported that the most common types of soil degradation in Europe are the loss of soil organic carbon, the loss of soil biodiversity, and soil erosion by water (ESDAC, 2023). These processes have a significant impact on soil health, resulting in reduced crop productivity, increased soil erosion, and degraded water quality. Furthermore, additional research showed that most unhealthy soils in Europe are affected by more than one type of soil degradation. Therefore, reducing soil erosion and increasing soil organic carbon stocks can enhance resilience by improving soil health, water and air quality, biodiversity and crop productivity.

Maps at European scale of soil erosion by water (Panagos et al., 2015), soil erosion by wind (Borrelli et al., 2017) and erosion risk for arable land in Switzerland (FOAG, 2019) were used to assess soil loss in agricultural land. Soil losses greater than 2 t ha^{-1} yr^{-1} were considered areas under higher risk of soil erosion (Panagos et al., 2020).

Potential and actual soil organic carbon SOC stocks were considered to estimate SOC ratios based on datasets from Lugato et al. (2014a; 2014b). Areas showing a ratio less than 0.4 were defined as areas under risk, as those areas would be 60% below their capacity to store SOC under optimal conditions as outlined by ESDAC (2023).

4.3.2. Risk of functional biodiversity loss

Biodiversity, pest control index, potential threats to soil biodiversity and pollinator potential were included in the analysis of pressures. Natural pest control is important for crop productivity and food security, as it reduces crop losses and the need for pesticides. Soil biodiversity is also essential for soil health, as it influences soil formation, decomposition, nutrient cycling, water regulation, and pest control (Orgiazzi et al., 2016). Pollinators are necessary for crop yield and quality.

For the whole extent of the countries considered in this study, no consistent and detailed spatial data bases on species richness, diversity, or related direct indicators of biodiversity are available. Therefore, other indicators expressing functional aspects of biodiversity were used as proxies for biodiversity related risks which are available for Europe. One indicator reflects the natural pest control (Rega et al., 2018) and the other represents crop pollination potential (Vallecillo et al., 2020).
For both datasets, the lower two quintiles of the values' distribution were used to identify areas under risk. This means that areas with lower values have a higher risk of pest outbreaks and reduced crop yields due to lower potential for supporting natural pest control services and pollinators, respectively.

Additionally, potential threats to soil biodiversity were assessed based on Orgiazzi et al. (2016). The three major components of soil biodiversity were assessed: 1) soil microorganisms, 2) soil fauna, and 3)

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biological functions. Potential risk was ranked into five classes using the quantile classification method, according to Orgiazzi et al. (2016): low, low-moderate, moderate, moderate-high, and high levels. Areas falling into moderate-high and high levels were considered as areas under risk.

The geographical coverage of the biodiversity maps sometimes excluded countries such as Croatia, Cyprus and Switzerland, leading to a lack of data for these areas. To address this issue, the mean values of the potential areas for each of the biogeographical regions in Europe were calculated and assigned to the potential areas of the same biological regions in the countries lacking data.

4.3.3. Water related risks

To assess water-related risks in Europe, the global dataset of irrigated areas (FAO, 2013) was used to identify the percentage of irrigated areas from the total agricultural land. Regions where more than 30% of the total agricultural land was irrigated were defined as potential areas under risk, as exceeding this limit could lead to a critical use of this natural resource (ESDAC, 2023).

The EU Soil Observatory (EUSO) identified nitrogen surplus as one type of soil degradation. The nitrogen concentration map of European agricultural soils (EEA, 2022a) and the Swiss map of nitrogen inputs into waters (FOEN, 2015) were used to assess whether excessive levels of nitrogen existed in the soil and water. A critical threshold of over 50 kg N ha^{-1} was used to identify areas under high risk (UBA, 2014; ESDAC, 2023).

Reducing irrigated areas and managing nitrogen excess are crucial for building agricultural resilience. These actions improve water availability and quality, mitigate climate change, and boost biodiversity. Strategies like minimizing nitrogen and phosphorus leaching, conserving soil moisture, diversifying crops, modifying microclimates, and adopting sustainable intensification methods further enhance this resilience, ensuring agriculture can adapt to a changing climate (Smith and Olesen, 2010; Godfray and Garnett, 2014).

4.3.4. Climate change risks

To conduct an analysis of the risks associated with climate change, specific variables such as the average annual temperature, aridity index, drought frequency and heavy precipitation were chosen. Some of these variables were used by Schnabel et al. (Schnabel et al., 2021) to describe climate change in Europe and its effects on MF/AF systems. By comparing present climate conditions with projected future conditions across multiple scenarios, an estimation of the net change was assessed.

The sixth Assessment Report published by the Intergovernmental Panel on Climate Change (Lee et al., 2021) was considered to select the climate change-related indicators. Changes in key climate impacts within the different European sub-regions include an increase in pluvial flooding in Northern, Western and Central Europe, an increase in fire weather in Eastern Europe and an increase in hydrological, agricultural and ecological droughts in the Mediterranean bioregion.

Climate change affects agriculture in various ways, influencing various aspects such as altering crop phenology, water availability, pest and disease incidence, and crop yield and quality. Different studies

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have highlighted the significance of climate change on agricultural productivity through temperature increases, changes in water availability, and the occurrence of extreme environmental events like floods, droughts, storms, cyclones, and landslides (Awopegba et al., 2022).

Regarding annual mean temperature, areas reporting an increase between 2 and 4 °C would be defined as areas under risk. Agroforestry systems could have a key role in these areas as they are reported to remain robust within an average temperature increase of up to 4 °C (Hart et al., 2012).

Climate datasets were obtained from the Copernicus Climate Change Service (Nobakht et al., 2019; Wouters, 2021; Wouters et al., 2021) and the European Environmental Agency (EEA, 2019). Actual data were estimated from the mean values for the period of 1970-2000, while future projections were calculated for different periods: 2021-2040 and 2041-2060. Different climate scenarios were considered to estimate the net change between actual climate and future projections.

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Table 5. Selection of environmental indicators to assess areas under risk in Europe, according to soil, biodiversity, water, and climate change variables.

Risk indicator	Description	Source	Coverage*	Resolution	Threshold	Threshold source
Soil	Soil erosion by water	(Panagos et al., 2015)	EU 27, UK	100 m	> 2 t ha^{-1} yr^{-1}	
	Soil erosion by wind		EU 27, UK	1000 m	> 2 t ha^{-1} yr^{-1}	(Panagos et al., 2020)
	Soil erosion map of Switzerland	(Borrelli et al., 2017)	CH	2 m	> 2 t ha^{-1} yr^{-1}	
	Loss of soil organic carbon		all Europe	1000 m	< 0.4 Ratio between actual and potential SOC stock	(Panagos et al., 2020)
Biodiversity	Potential threats to soil biodiversity	(FOAG, 2019)	EU 26, UK (without HR and CH)	500 m	"High" and "Moderate-High" level of risk were defined as Areas under risk	
	Pest control index		all Europe (without CY)	100 m	First two quintiles of the values' distribution	(Panagos et al., 2020)
	Pollinator potential	(Lugato, Bampa, et al., 2014; Lugato, Panagos, et al., 2014)	EU 27, UK (without CH)	1000 m	First two quintiles of the values' distribution	
Water	Irrigated areas		World	100 m	>30% irrigated land	(ESDAC, 2023)
	Nitrogen surplus	(Orgiazzi et al., 2016)	EU 27, UK, CH	100 m	> 50 kg N ha^{-1} yr^{-1}	
	Nitrogen surplus Switzerland		CH	100 m	> 50 kg N ha^{-1} yr^{-1}	
Climate change	Annual mean temperature	(Rega et al., 2018)	All Europe	100 m	2-4ºC	(Orgiazzi et al., 2016)
	Aridity index		All Europe	100 m	After dataset analysis	
	Drought frequency	(Vallecillo et al., 2020)	All Europe	100 m	After dataset analysis	
	Heavy precipitation		All Europe	100 m	After dataset analysis	

*EU 27: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden; CH: Switzerland; CY: Cyprus; HR: Croatia; UK: United Kingdom.

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4.4. Determination of target areas

After combining the environmental indicators, heat maps will be produced to highlight the intensity of environmental risks. Data will be analysed considering the different biogeographical regions present in Europe: Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian and Steppe. Areas with a high concentration of risks will be determined as target areas to introduce MF/AF.

An analysis will also be performed by land use/land cover category considering the concentration of the risks associated with croplands, permanent crops, and pasture lands separately. This analysis will be useful to identify those land use categories with high concentration of risks and determine the appropriate actions necessary to introduce MF/AF and mitigate environmental risks.

Once the target areas under risk are identified, the woody landscape elements described on WP1 (Schnabel et al., 2021), using the Land Use/Cover Area frame Survey (LUCAS), will be used to detect which of the target areas contain these features and their characteristics. Spatial analysis will help in this task. Moreover, complementary to the woody landscape elements obtained from LUCAS, the High-Resolution Small Woody Features dataset, created by the Copernicus Land Monitoring Service in 2019, will be used because it provides additional information on the spatial distribution of those features.

4.5. Social and economic aspects

Additionally, relevant social and economic indicators will be assessed in the defined target areas. This analysis will provide insights into the social and economic determinants posed to the possibilities of introducing MF/AF in these areas and the relationships between the environmental indicators of risk and those socio-economic aspects. Some variables that will be considered are related to aspects such as demography, education level, income level and land tenure systems. Among them, population projections, projected old-dependency ratio, population density, income distribution, agricultural income, employment rates, will be used; most of them provided by Eurostat databases. The spatial resolution of the social and economic datasets presents a challenge for integrating it with the environmental datasets. While the environmental data provides a higher spatial resolution, Eurostat's data on socio-economic variables is only available at the NUTS 2 regional level. This discrepancy in spatial resolution makes difficult to directly combine the environmental pressure analysis with a detailed characterization of the socio-economic background in the target areas.

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5. Land use change models at pilot level

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5.1. Overview

While target regions for introducing MF/AF systems to increase resilience are identified spatially in Sub-task 3.3.1, the transition towards a particular land use system will occur at the plot/farm decision level. In complex systems such as MF/AF, "one size fits all" does not apply, neither in terms of species/system combination and dynamics, nor because climate change resilience has different meanings according to the different environmental regions. Different models of land use change will be provided for European regions affected differently by climate change to evaluate pathways towards increased resilience to climate change. Therefore, this sub-task will focus on delivering a suite of problem-solution based land use change models to deliver a close-to-practice ensemble for farmers to use.

In the context of AGROMIX, the 'problem' we are addressing is the impact of climate change on agricultural and forestry systems, and the 'solution' is a change in land-use towards a more resilient system. The land-use models we are focusing on are mixed farming and agroforestry, and we will use the classification scheme developed in the AGROMIX Task 1.4 (Schnabel et al., 2021) to embody the diversity of different systems (Figure 10, Section 5.2.1). Real-world examples of the different land-use models will be collated, bringing together case studies captured in the AGROMIX project as well as from other sources including other EU projects, EIP Focus Groups, European agroforestry associations, and from expert knowledge (Section 5.2.3).

To match the land-use models as 'solutions' to the climate change impacts 'problems', we will consider two questions for each land-use model:

- ***Which specific climate impact drivers, risks and impacts can the land-use model increase resilience to?*** To answer this question, we will focus on the climate impact drivers identified in the IPCC AR6 (Bednar-Friedl et al., 2022) for Northern Europe, Western and Central Europe and the Mediterranean (Section 5.3). The resilience of the different agroforestry and mixed farming models to the climate impact drivers (mean warming, heat extremes, cold extremes, mean precipitation, heavy precipitation, droughts and severe wind storms) and associated impacts (e.g. flooding, heat stress, wildfires) will be assessed through an expert consultation process using the Delphi technique (Section 5.5) supported by a review of scientific evidence through a literature review (Figure 9).
- **What are the implementation, management and economic implications of a change in land-use towards a more climate change resilient land use model?** While a change in land use may increase resilience to climate change, implementing agroforestry and mixed farming systems present certain challenges during the establishment phase, for on-going management and may impact financial viability (positively or negatively). This will depend both on the initial land use and the nature of the agroforestry or mixed farming system. To address this question, we will ask the experts involved in the Delphi process to assess the costs of establishment, ease of

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management and financial viability of the different land use models compared with the arable, livestock, orchard or forestry baseline (Figure 9).

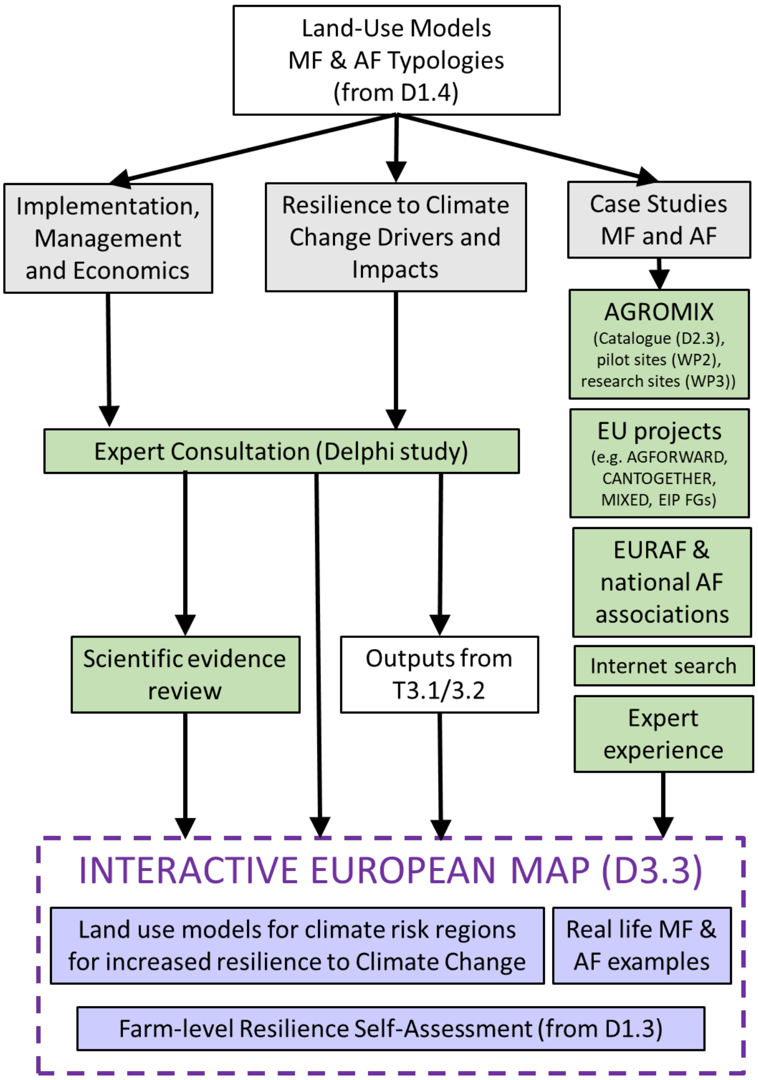

Figure 9. Subtask 3.3.2 activity flow with links to previous deliverables (D1.3, 1.4) and ongoing tasks (T3.1, 3.2). Green boxes indicate the activities to be carried out in the Subtask 3.3.2. Purple boxes refer to the second Deliverable from this task, D3.3

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5.2. Land-use models, land-use change and case studies

5.2.1. Land-use models

The land-use models to consider in this work are agroforestry systems and mixed farming systems. AGROMIX defines agroforestry as *'the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from the resulting ecological and economic interactions'*, while mixed farming is defined as *'the practice of deliberately integrating crop and livestock production to benefit from the resulting ecological and economic interactions'* (Puttsepp et al., 2022). A farm may include multiple systems, with or without interactions between them.

The term 'agroforestry' encompasses a wide diversity of designs, components and combinations and AGROMIX has developed a classification scheme that first differentiates between the function and/or distribution of the tree component (i.e. high value trees, permanent tree crops, forest trees, trees in rows or linear features such as hedgerows) and then considers the agricultural component(s) (i.e. crops or livestock or both) (Figure 10).

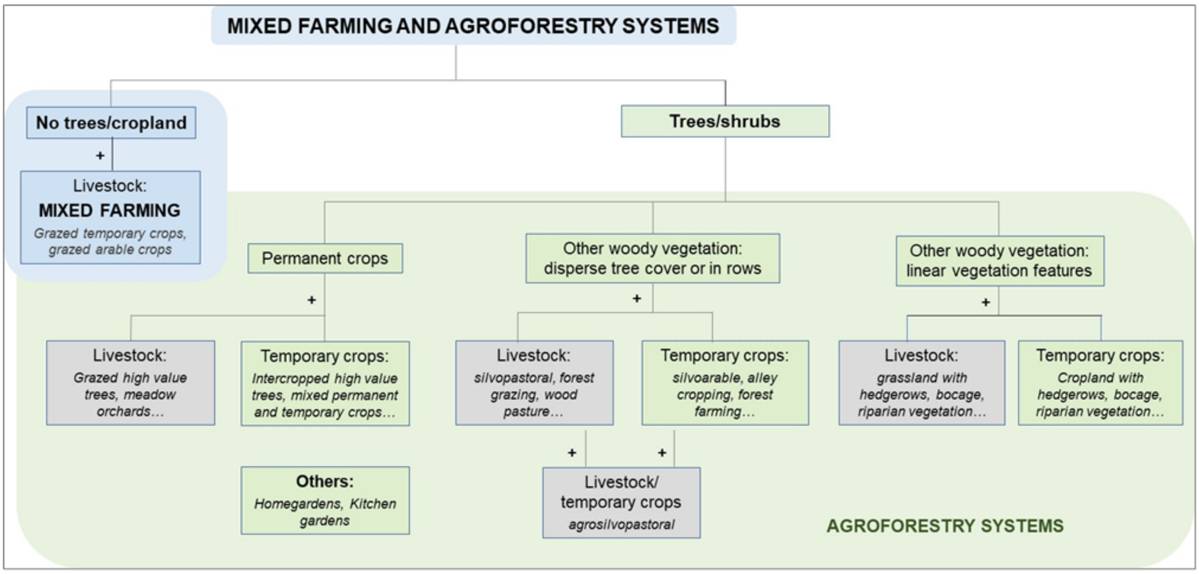

Figure 10. Classification of agroforestry and mixed farming systems developed in AGROMIX Task 1.4 (Schnabel et al., 2021)

An alternative classification approach was developed by Lawson et al (Lawson, Brunori, et al., 2016; Lawson, Curran, et al., 2016) and subsequently adopted by the European Agroforestry Federation, which starts with the location of the trees (within fields vs between fields) and then differentiates between land use, i.e. agroforestry on forest land vs agricultural land (Table 6).

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Table 6. Agroforestry classification developed by Lawson et al, 2016a, b

	Agroforestry system	Land use classification	
		Forest land	**Agricultural land**
Trees within fields	Silvopastoral	Forest grazing	Parkland, wood pasture, orchard grazing, individual trees
	Silvoarable	Forest farming	Alley cropping, alley coppice, orchard intercropping, individual trees
	Agrosilvopastoral	Mixture of the above	
Trees between fields	Hedgerows, shelterbelts & riparian buffer strips	Forest strips	Shelterbelts, hedges, riparian tree strips

While the two approaches differ, there is considerable alignment with the final land use models, and we will use a combination of the two approaches (Table 7). Departing slightly from the AGROMIX classification, we will exclude the terms ‘silvoarable’ and ‘silvopastoral’ as these are overarching terms, and ‘Bocage’ agroforestry is a regional term for hedgerows with either crops or livestock, so this will also be removed. We will integrate ‘meadow orchards’ with the more general term ‘grazed permanent crops’. Finally, we will add ‘shelterbelts’ as a typology within the linear features group. In total we will have 11 land-use models, i.e., 10 agroforestry typologies and one mixed farming.

Table 7. Land use models used in this task

Tree component	Agricultural component	Land use model	Examples
None	Livestock + arable	Mixed farming	
Permanent woody crops	Livestock	Grazed orchards	
	Temporary crops	Intercropped orchards	

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Tree component	Agricultural component	Land use model	Examples
Other woody vegetation, dispersed tree cover or in rows	Livestock	Forest grazing	
		Wood pasture	
	Temporary crops	Forest farming	
		Alley cropping	
	Livestock + temporary crops	Agrosilvopastoral	
Linear woody features	Livestock *or* temporary crops	Hedgerows	
		Riparian buffers	
		Shelterbelts	

These land use models can be thought about as varying in the balance of the three components (trees, livestock and annual crops) (Figure 11). They can also be considered on a gradient of tree cover, ranging from potentially closed canopies in forest farming and forest grazing systems, through to lower levels of canopy cover in wood pastures and grazed or intercropped orchards, to alley cropping and linear woody features where the agricultural components are dominant, and finally to the no-tree mixed farming system. The boundaries between the different models can be very blurry. Such gradients of tree cover and integration may have implications for climate change resilience and practical implementation and management of the land use models and as part of the Delphi process, experts will be asked to consider the resilience of each of the land use models compared to the agricultural or forestry baseline (Section 5.5).

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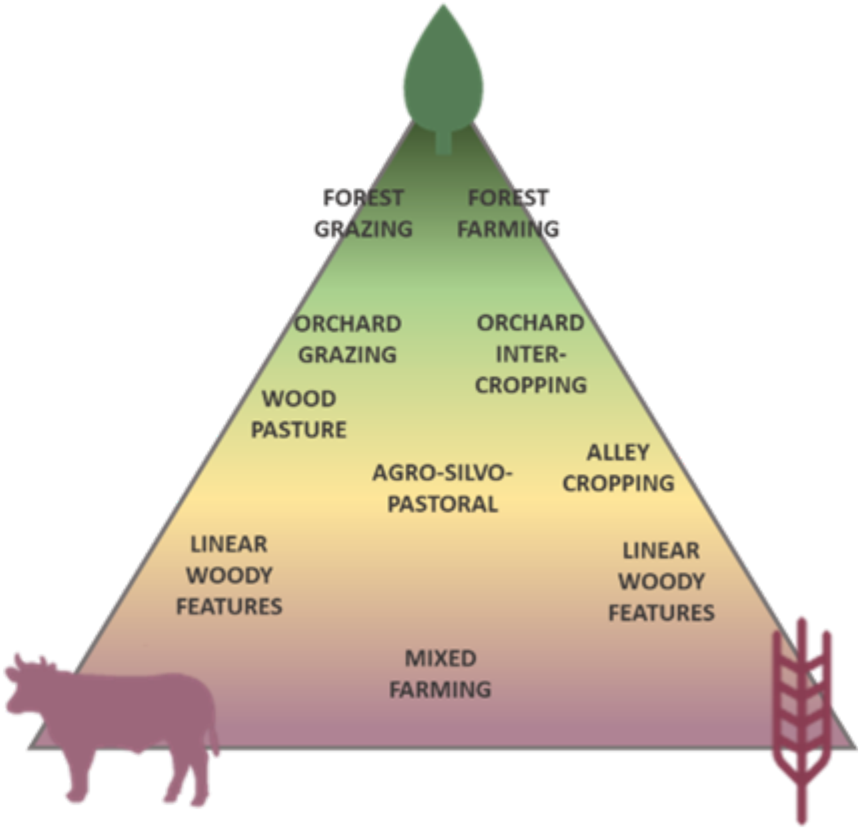

Figure 11. Land use models of agroforestry and mixed farming vary in their balance of the tree, animal and temporary crop components (adapted from Burgess and Rosati, 2018)

5.2.2. Land-use change

The baseline land-use systems we will consider are 'non-mixed' systems, whereby the introduction of additional components will potentially increase resilience to climate change impacts. In addition to three agricultural baselines (arable, livestock and orchards (includes vines and olives)), we also include a forestry baseline. The pathways of land-use change from the 'non-mixed' baselines to the resulting land-use models are shown in Figure 12.

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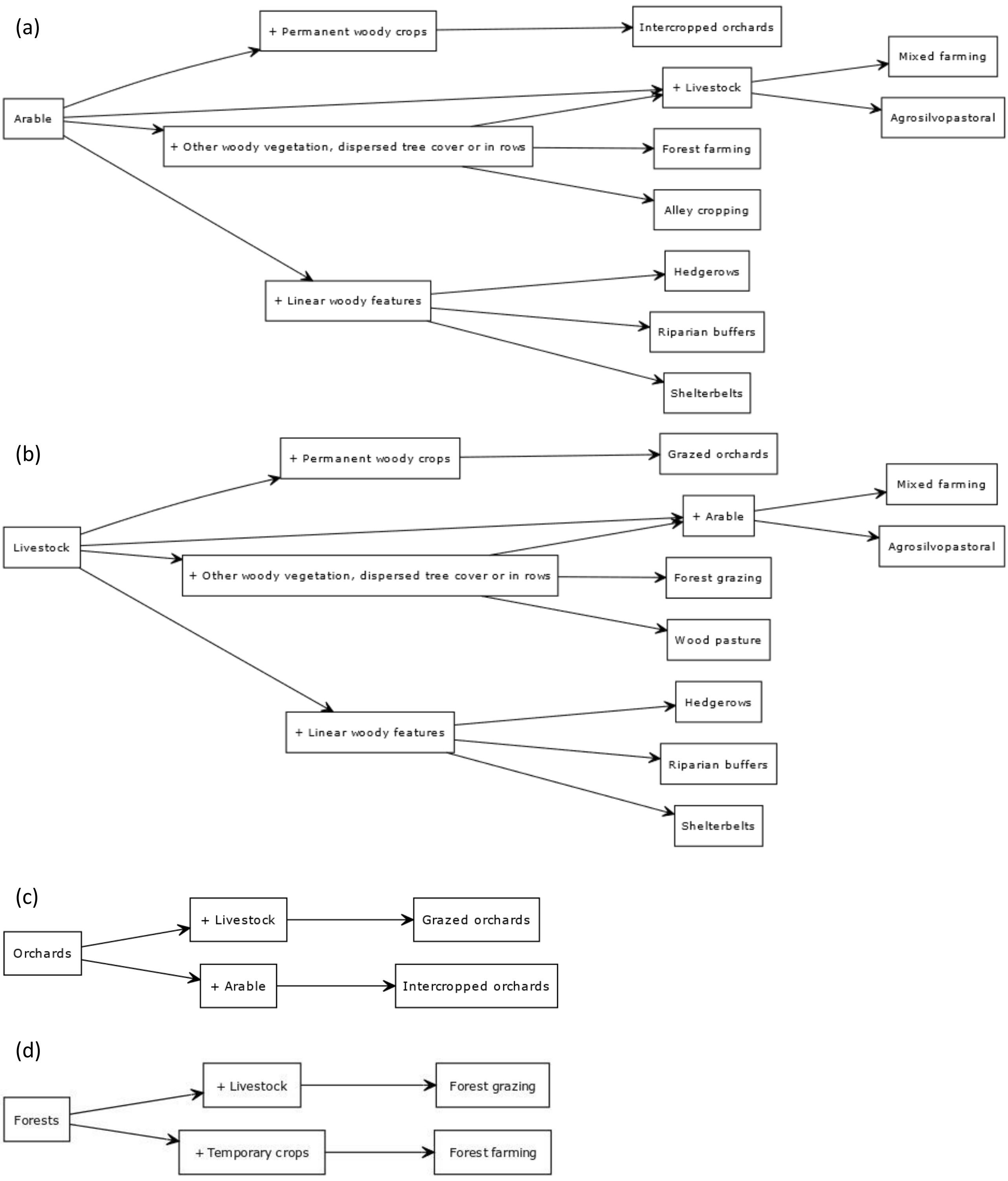

Figure 12. Land-use change pathways for (a) arable, (b) livestock, (c) orchard and (d) forestry baselines

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5.2.3. Case studies

Real-world case-studies of mixed farming and agroforestry across Europe will be collected and presented in the interactive map (Deliverable 3.3) to demonstrate the practical application of the land-use models and provide inspiration. A common template for each case-study will be developed to include details of the different components (e.g., arable crop species, livestock species and breeds, tree species and densities), outputs produced (food, feed, timber) and, where possible and available, photos and links to existing on-line resources (e.g. if the farm has a website, factsheets or videos). The case-studies will be classified according to the typologies in Section 5.2.1. The aim is to identify at least one case-study for each land-use model in each of the three IPCC regions of Europe (Northern Europe, Western and Central Europe, Southern Europe), although for some land-use models, it is likely that there will be several examples. A range of sources will be investigated for case-studies:

- The AGROMIX project. Within AGROMIX, agroforestry and mixed farms are included in a number of tasks and work packages. These include 78 case-studies from 12 countries included in the Task 2.3 Deliverable 2.3 Catalogue which includes a detailed description of the individual farms and farm networks, the 12 pilot farms and networks included in the co-design process of Task 2.2 and the six experimental sites involved in WP3.
- Other EU Projects. As well as the two 'sister' projects, **MIXED** and **STARGATE**, which are addressing the same EU Horizon 2020 call on climate smart and resilient farming, we will review case studies featured in previous and current relevant projects, for example, **CANTOGETHER** (mixed farming), **AGFORWARD** (agroforestry), **AFINET** (agroforestry), **SustainFARM** (agroforestry), **DIGITAF** (agroforestry) and **Re-Forest** (agroforestry).
- EIP-AGRI Focus Groups and other EC online resources. There have been two relevant specific EIP Focus Groups: **Mixed farming systems: livestock/cash crops** and **Agroforestry: introducing woody vegetation into specialised crop and livestock associations** and various case-studies are included within the various Focus Group outputs. Other EIP-AGRI resources also feature agroforestry and mixed farming case-studies, for example **'Inspirational ideas'** factsheets.
- **The European Agroforestry Federation** (EURAF) and national agroforestry associations. EURAF is a federation of national agroforestry associations with other 500 members from 24 different European countries. Their website includes a section on '**Featured Farms**' as well as a **map of Europe with agroforestry farms** classified by agroforestry category and with a brief description. The affiliated national agroforestry associations will also be reviewed for case studies, for example **DeFAF in Germany**, the **Farm Woodland Forum** in the UK and **Agroforestry Vlaanderen** in Belgium.
- Expert experience and knowledge. Finally, we will ask agroforestry and mixed farming experts involved in the Delphi process (Section 5.5) to suggest additional case-studies, particularly if we have a lack of specific land-use models for their region.

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5.3. Climate impact drivers, impacts and risks

5.3.1. Observed and projected direction of change in climate impact drivers

In line with Task 1.4 and Deliverable 1.4, we use the observed and projected changes in European climate impact drivers identified by the Intergovernmental Panel on Climate Change (IPCC), specifically Chapter 13 (Europe) of the Sixth Assessment Report (Bednar-Friedl et al., 2022). The AR6 recognises four subdivisions of land area for Europe (Figure 13); we will focus on Northern (a), Western and Central (c), and Southern Europe (Mediterranean).

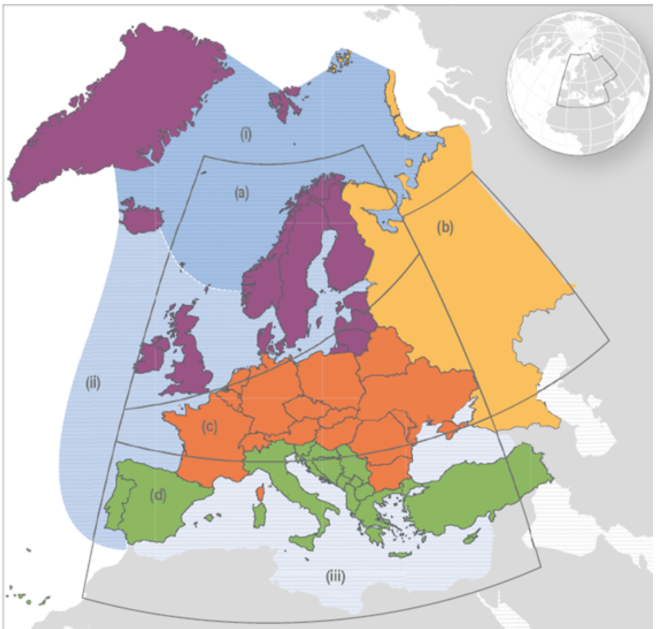

Figure 13. Geographical subdivision of land (a-d) and ocean (I-III) regions used by IPCC AR6 (from Bednar-Friedl et al., 2022). For the framework we focus on Northern Europe (a; purple), Western and Central Europe (c, orange) and Southern Europe (d, green)

The IPCC AR6 defines climate impact-drivers (CIDs) as conditions of the physical climate system (e.g. means, events, extremes) that affect society and/or ecosystems. For each sub-region, the AR6 describes and quantifies changes to climate impact drivers according to Global Warming Levels (GWL); Figure 14 shows the projected direction of change in climate impact drivers at 1.5°C and 4°C GWL as well as observed changes. Within the framework, we will consider the resilience of the land-use models to the observed and projected changes in the climate impact drivers and associated observed impacts and projected risks. In some cases, the projected changes are the same across the three sub-regions (e.g., increasing mean warming and heat extremes, decreasing cold extremes) while in other cases, the direction of change is different in the sub-regions (e.g. increasing mean precipitation in Northern Europe vs decreasing mean precipitation in the Mediterranean; Figure 14) or a change is predicted for one sub-region only (e.g., droughts in the Mediterranean). Such regional variation will be included within the review of resilience.

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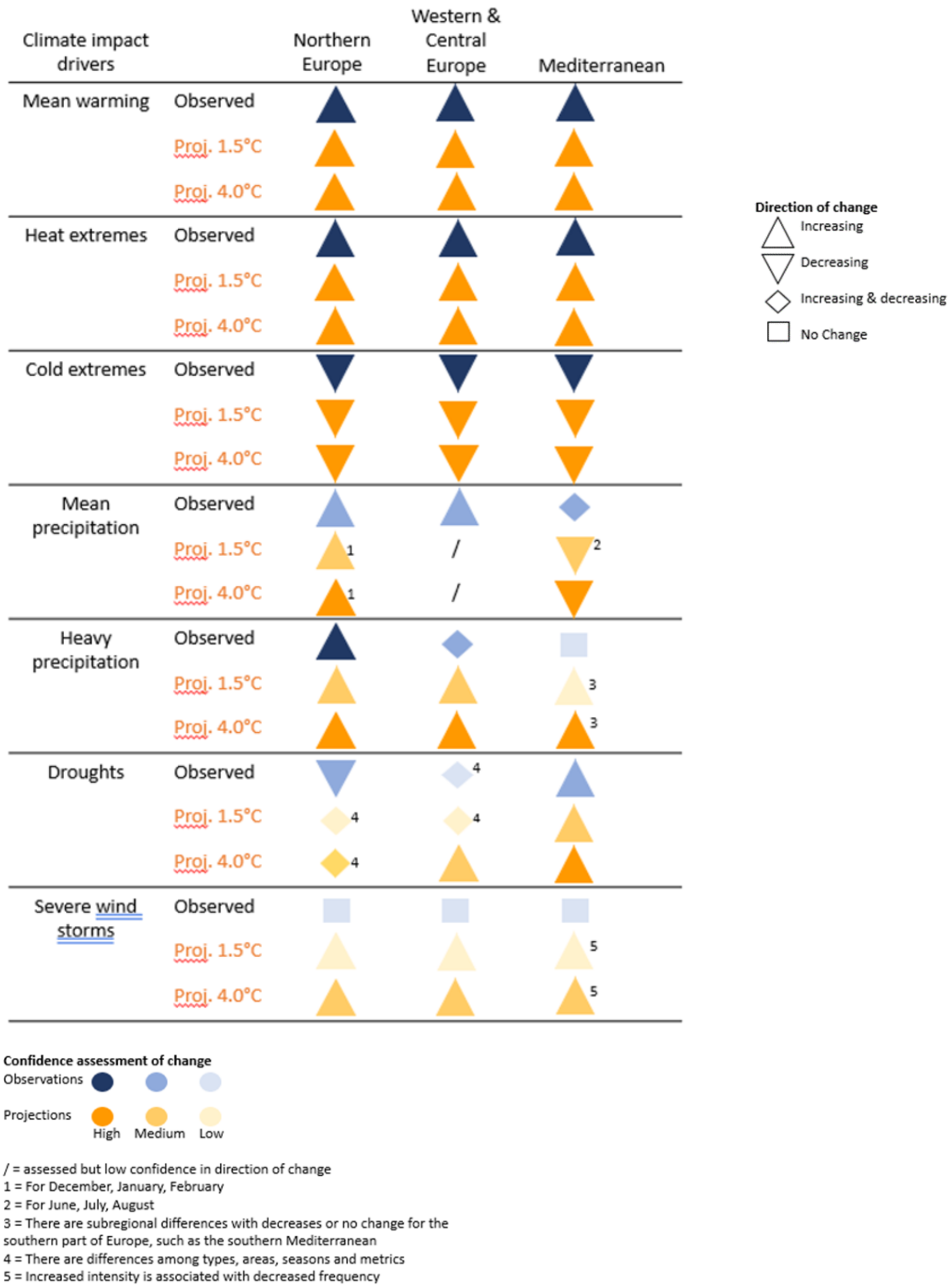

Figure 14. Observed and projected direction of change in climate-impact drivers at 1.5°C and 4°C GWL for European sub-regions (Bednar-Friedl et al 2022)

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5.3.2. Climate impact drivers, observed impacts and projected risks

The IPCC AR6 identified observed impacts and projected risks of the climate impact drivers (Table 8), with many impacts/risks having multiple drivers which may interact to either increase the level of impact or cancel out any potential impact (Table 9).

Table 8. Overview of observed impacts and projected risks from climate impact drivers (summarised from Bednar-Friedl et al., 2022)

	Observed impact/projected risk										
Climate impact driver	Range shift	Changes in phenology	Heat stress	Water stress	Fire incidence increase	Soil erosion increase	Flooding	Reduced pollination services	Pest & disease increase	Labour productivity	Forest, crop and livestock productivty
Mean warming	x	x	x	x	x	x		x	x		
Heat extremes			x	x	x	x		x		x	x
Cold extremes									x		
Mean precipitation	x				x						
Heavy precipitation						x	x				x
Drought			x	x	x	x		x			x
Severe wind storms						x					

Table 9. Overview of major impacts/risks and direction of change in Europe (summarised from Bednar-Friedl et al., 2022)

Impact/Risk	**Med-iterranean**	**Western & Central**	**Northern**
Range shifts	↑	↑	↕
Changes in phenology	↑	↑	↑
Heat stress	↑	↑	↑
Water stress	↑	↑	↑
Incidence of fire	↑	↑	↑
Soil erosion	↕	↑	↑
Flooding	↕	↑	↑
Pollination services	↕	↕	↕
Pests and diseases	↑	↑	↑
Labour productivity	↓	↓	↓
Forest, crop and livestock productivity	↓	↕	↕

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5.3.3. Assessing resilience to climate-impact drivers

The IPCC identifies agroecological systems, including agroforestry, as highly effective adaptation options that enhance resilience to climate change (Bednar-Friedl et al., 2022). But what are the particular characteristics or mechanisms of these agroecological systems that enhance their resilience, i.e., reduce their vulnerability to climate change, compared with conventional systems?

The IPCC 2007 defines vulnerability in the context of climate change as "*the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity*". The IPCC (2007) identifies the three main components of vulnerability as *exposure* i.e., in what way and to what extent a system is exposed to climate variations, *sensitivity* i.e. the extent to which a system is affected (negatively or positively) by climate variability or change, and *adaptive capacity* i.e. the potential of a system to adjust to climate change (Figure 15). Exposure and sensitivity together will determine the *potential impact* of climate change on a system, but vulnerability of the system is modulated by the capacity of the system to adapt (Fellmann, 2012).

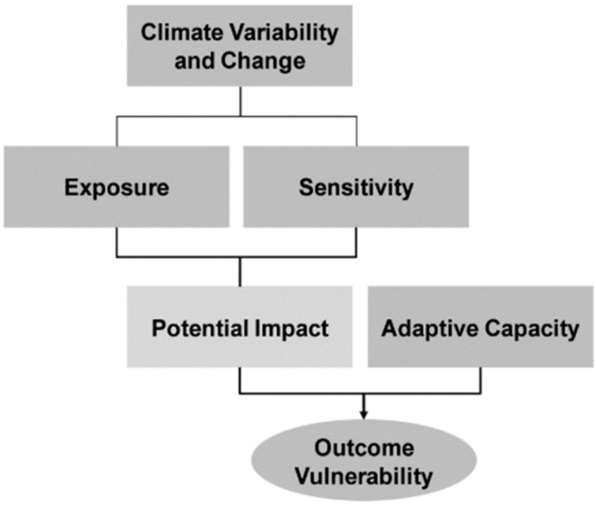

Figure 15. Vulnerability framework (Fellmann, 2012)

Agroforestry can potentially reduce vulnerability (and increase resilience) by reducing *exposure* to climate impact drivers, for example, by providing shade and thus reducing exposure to extreme temperatures (Jose, Gillespie and Pallardy, 2004; Moreno Marcos et al., 2007), or by providing shelter and thus reducing wind speeds (Williams et al., 1997; Tamang, Andreu and Rockwood, 2010). Agroforestry can also reduce the *sensitivity* of the farming system to the climate impacts for example, by supporting better soil structure and higher soil organic matter levels (Young, 1985), therefore reducing the risk of soil erosion, increasing water infiltration and reducing surface water runoff and consequently reducing flood risks (Seobi et al., 2005; Anderson et al., 2009). By supporting higher biodiversity, agroforestry systems could also potentially reduce *sensitivity* of the farming system to impacts of climate change on pollination services and increased pest and disease risks (Jose, Gillespie and Pallardy, 2004; Staton et al., 2019, 2021; Varah et al., 2020). Finally, due to the higher diversity of the farmed system (i.e., combining tree and agricultural production), we can suggest that agroforestry systems have a higher *adaptive capacity* than

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the agricultural or forestry baseline by opening more opportunities for change. For Mixed Farming systems, the potential for increasing resilience is less obvious, and is likely to be related to better soil health and lower reliance on external inputs such as feed and nutrients reducing the *sensitivity* of the system, while system diversity increases its *adaptive capacity* (EIP-AGRI Focus Group, 2017).

While there has been considerable research on the mitigation and adaptation potential of agroforestry systems (Hernández-Morcillo et al., 2018; Kay et al., 2019; Reyes-Palomo et al., 2022), the resilience potential of agroforestry and mixed farming, particularly in a European context, has not been well addressed, perhaps due to the complexity and diversity of these systems and the challenges of measuring or modelling resilience. We aim to address this gap by engaging experts within a Delphi process to assess the resilience of the different agroforestry and mixed farming models to the climate impact drivers and identify the key mechanisms or properties of these agroecological systems that support higher resilience/reduced vulnerability (Section 5.5). As a final step, a literature review will identify scientific evidence to support the key mechanisms or properties identified through the expert consultation; this will be complemented by research outputs from other tasks within AGROMIX WP3 which are measuring and modelling biophysical indicators of resilience to climate change in six experimental AF/MF sites (Task 3.1).

5.4. Implementation, management and economic implications of land-use change

While agroecological systems have received considerable interest, and in some cases, considerable policy support and promotion, implementation by farmers is still limited, with mixed farming systems representing 11.1% of agricultural systems in the EU (Schnabel et al., 2021) and agroforestry systems just 9% of the utilised agricultural areas (den Herder et al., 2017). Studies focusing on farmers' perceptions of agroforestry highlight concerns about ease of management, costs of establishment and financial performance, compared with the conventional or monoculture alternatives (Graves et al., 2008; EIP-AGRI Focus Group, 2017; García de Jalón et al., 2018; Rois-Díaz et al., 2018). Therefore, it is important to evaluate the consequences of land use change in terms of implementation, ongoing impacts on management and financial performance of the different land use models; as part of the Delphi process, experts will be asked to assess the agroforestry and land use models with regards the costs of implementation, ease of management and financial performance compared with the agricultural or forestry baseline. This will be complemented by research outputs from Task 3.2 in WP3 which is modelling bio-economic performance of six experimental AF/MF sites.

5.5. Expert consultation

5.5.1. The Delphi method - overview

As there are research and evidence gaps in knowledge concerning the resilience of mixed farming and agroforestry land use models to climate change, an iterative expert knowledge-based Delphi method will be used. The Delphi technique is “a method of structuring a group communication process so that the process is effective in allowing a group of individuals as a whole to deal with a complex problem” (Hugé

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et al., 2010). By organising and structuring expert group debates on complex issues, the Delphi method makes it possible to channel often diverse views and opinions into a consensus through an iterative feedback process. Although implementation can vary between studies, typically a Delphi study will comprise two or more rounds of structured questionnaires, each followed by aggregation of responses and anonymous feedback to the participants (Mukherjee et al., 2015). After each questionnaire round, participants are asked to review and confirm or amend their previous responses, taking into account the opinions and elements that were suggested by the group during the preceding round. The process is repeated until a consensus emerges; the most common definition for consensus is a threshold of percentage agreement (usually 75% as the median threshold (Diamond et al., 2014)), which is usually achieved after two or three rounds of questionnaires. The Delphi method can be carried out entirely online, which can make it efficient in terms of both time and costs, although a successful outcome is only possible through careful construction of the process. Therefore, a key benefit of this approach is that it allows the collection of information from experts who are not able to be brought together physically because of wide geographic distribution or different time zones (Mukherjee et al., 2015).

5.5.2. Objectives of the Task 3.3 Delphi

1) Consensus on the resilience of land use models (i.e. AF/MF) to climate impact drivers and associated impacts compared with baseline scenarios (i.e. arable/livestock/orchards/forestry).
2) Identification of key mechanisms and properties of AF/MF systems that increase resilience.
3) Identification of additional case studies of AF/MF land use models.
4) Consensus on the implementation, management and economic implications of a change in land-use towards a more climate change resilient land use model.

5.5.3. Selection and engagement of participants

The selection of 'experts' for participation in the Delphi process should be based upon objective criteria defined prior to the study. Within the context of the AGROMIX project and Task 3.3, experts need to have knowledge and understanding of (1) European agroforestry and mixed farming systems, (2) climate impact drivers and climate change impacts and (3) concepts of resilience of farming systems to climate change. In terms of numbers of participants, while the respondent panel size is not required to be a statistically representative sample since the panel representativeness is judged based on the respondents' attributes, it is suggested that the number of participants should be between seven and fifty or over (Powell, 2003). Following the sub-division of Europe used within the climate change projections of the IPCC, we will aim for at least seven participants for each of the three regions; Northern, Western and Central, and Southern Europe (Mediterranean), i.e., a minimum of 21 experts. An initial list of experts to be invited will be identified from partner organisations involved in the AGROMIX project, the sister projects MIXED and STARGATE, from the new Horizon Europe agroforestry projects, DigitAF and ReForest, and from country delegates of the European Agroforestry Federation.

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5.5.4. Delphi process

First, an email will be sent to the identified experts, explaining the goal and protocol of the Delphi study and inviting them to sign up to participate in the study. To encourage engagement throughout the multiple rounds of surveys, there will be an invitation for those who contribute fully to be added as co-authors to a peer-reviewed paper that is foreseen as an output of the study. When signing up, participants will be asked to indicate which of the climatic regions they are most familiar with - they will have the option to choose more than one. This will enable us to ensure adequate coverage of all three climate zones (minimum of seven experts per zone).

While the expert engagement process gets underway, the first round of the on-line survey will be formulated and trialled. The survey will be divided into four sub-sections; the first subsection will focus on the land use change from an arable baseline to AF/MF (Figure 12a), the second on land use change from a livestock baseline to AF/MF (Figure 12b), the third on land use change from an orchard baseline to AF/MF (Figure 12c), and the fourth on land use change from a forestry baseline to AF/MF (Figure 12d). Each subsection will contain 10 questions - seven relating to resilience of each of the AF/MF systems against climate impact drivers and their associated impacts compared to the baseline, and three relating to the implementation, management and financial viability of the systems. Each of the seven questions on resilience to the climate impact drivers will have a five-point scale answer ranging from 'Much lower resilience' to 'Much higher resilience', as well as an option to choose 'I don't know/unknown' (Figure 16). Experts will be asked to suggest the mechanisms or properties of each AF/MF system that determines the level of resilience, with references where appropriate, plus the opportunity to add notes or caveats. For the three questions on implementation, management and financial viability, the answer options will also be on a five-point scale but tailored to the question. Descriptions of the land use models, and explanations of the climate impact drivers and associated impacts will be provided, and where necessary adapted for the specific climate region (e.g., where climate impact drivers and impacts differ between regions). As a final step in the first-round survey only, experts will be asked to contribute to the real-world case studies of the land-use models (Section 5.2.3).

Question 1. Resilience of the land use model to **mean warming** compared with an arable baseline

LAND USE MODEL	Much lower resilience	Lower resilience	Same resilience	Higher resilience	Much higher resilience	Unknown	Mechanisms/ properties (with references)	Caveats/notes
Mixed farming	O	O	O	O	O	O		
Intercropped orchards	O	O	O	O	O	O		
Alley cropping	O	O	O	O	O	O		
Agrosilvopastoral	O	O	O	O	O	O		
Forest farming	O	O	O	O	O	O		
Hedgerows	O	O	O	O	O	O		
Riparian buffers	O	O	O	O	O	O		
Shelterbelts	O	O	O	O	O	O		

Figure 16. Draft question format for the Delphi survey

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Either as part of the final round of the Delphi, or post-Delphi, the mechanisms and properties of AF/MF proposed by the experts as determinants of resilience will be classified as either increasing robustness, increasing adaptability or increasing transformability, and whether the outcome affects social, economic or environmental resilience. The exact wording and structure of the questions, and associated information, will be finalised following piloting with two or three experts. Once finalised, the first round of the on-line survey will be shared with the experts, who will be given a two to three-week period to complete the survey. Following closure of the first round, two weeks will be needed to analyse the results and prepare the second round, when each participant will be provided with the group results, including suggested mechanisms and caveats, and the opportunity to alter their initial responses. If consensus is not reached after the second round, a third round will be undertaken. It is foreseen that the entire process will be concluded within a six-month period.

5.5.5. Outcomes of Delphi

At the end of the Delphi process, we will have reached consensus on the level of resilience of the different land use models against each climate impact driver compared to the agricultural or forestry baselines, with the mechanisms or properties that determine the level of resilience identified and supported by references where possible. There will also be consensus on the implementation, management and financial viability of the different land use models compared with the baseline systems and each other, and additional real-world case studies identified and described.

In addition to a peer-reviewed paper, the results will feed into the second deliverable from this task, D3.3 Interactive European Map (Section 6).

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6. Interactive website

A new section of the AGROMIX project website is being developed with a tool organising the data and results of this task in an intuitive way, aimed primarily at the general public. The tool consists of three components, briefly described here: maps of the target areas, and a land use change module. By exploring the interactive maps, users can identify target areas for implementing AF/MF, before then considering land use change options for those target areas using the land use change module.

6.1. Interactive maps

The spatial modelling will generate a set of maps for suitable potential areas, areas of high environmental pressures, and finally target areas for the implementation of agroforestry, or mixed farming systems. Users will be able to browse between different maps to help them to understand the spatial extension of certain problems (i.e. the water, soil, biodiversity and climate risk maps), the location of the most suitable areas (i.e. the potential area map), and how these interact in the determination of target areas for the implementation of more resilient systems.

6.2. Land use change module and case study examples

Land use models and case study examples will be shown for "learning by example" guidance, while these will be linked and contextualised depending on the climate impact drivers and regions previously selected (Figure 17). The module will organise spatial data and display observed and projected climate impact drivers according to IPPC reports, identify the climate drivers and where they will be more likely to occur, and display a matrix of options related to agroforestry and mixed farming systems that could help to improve resilience of the systems. This will also show their performance in robustness, adaptability and transformability while facing climate impact drivers.

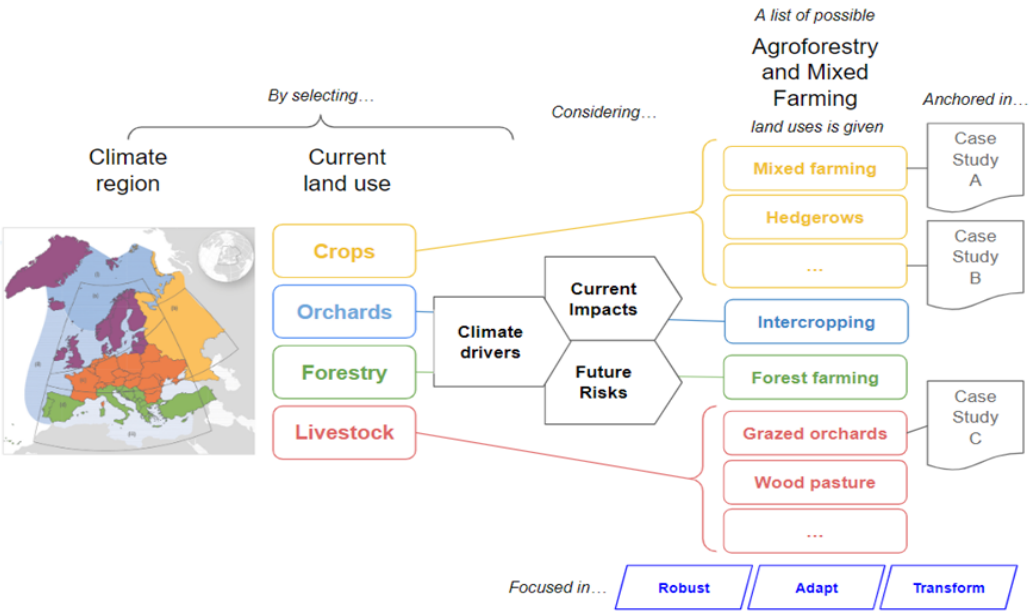

Figure 17. Conceptual model for Land Use Change module

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