Impact of climate change on mixed farming and agroforestry systems in Europe

Deliverable 1.4 – v1.4

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

Deliverable 1.4	**Impact of climate change on mixed farming and agroforestry systems in Europe**
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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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1 Executive Summary

The present report offers the results from research carried out in task 1.4 of the AGROMIX project and forms part of work package 1 which deals with the theoretical background and characterisation of mixed farming and agroforestry systems. The objectives of task 1.4 include a review of mixed farming and agroforestry (MF/AF) in Europe, their extension, spatial distribution, and recent changes. Furthermore, a physio-geographic characterisation of areas where these systems are practiced was carried out, as well as a review of climate change in Europe and how it will affect MF/AF. Furthermore, a GIS database which include a large number of variables was created which will serve for upscaling purposes in other tasks of the project.
A classification of MF/AF in Europe was proposed, recognizing seven classes: Silvopastoral, agrosilvopastoral, silvoarable, grazed permanent crops (PC), intercropped PC, grazed arable (temporary) crops and home gardens. The most recent data (2018) were used to analyse the extent and spatial distribution of MF/AF systems in Europe and the whole data set from 2009 to 2018 was applied in the study on temporal changes. Agricultural areas that were not included in the above classes, but which present woody linear features (WLF), were analysed separately, distinguishing three classes: arable land, grazed grasslands and permanent crops with WLF.
Land use/land cover data provided by Eurostat (LUCAS) were employed for analysis. However, the only mixed farming system which can be recognized with LUCAS was grazed arable crops, and hence, other MF systems cannot be considered in the geographical analysis of MF/AF systems. This is a serious limitation ignoring e.g. the combination of cropland with stabled livestock. In order to offer information on MF in Europe, farm structure data from EUROSTAT were analysed. In 2013, 11.2% of UAA in the EU were managed as MF. This value contrasts strongly with the estimated share of grazed arable crops as identified from the LUCAS database (0.43%).
Regarding the extent, the estimated total surface area occupied by agroforestry in the EU is 132,955 km^2, which represents 7.7% of utilized agricultural area (UAA). Silvopastoral land use is the dominant system, occupying nearly 78% of the total, followed by Home gardens with about 12%. Grazed arable crops present only 5.5% of the total MF/AF area and AF systems with permanent crops, either grazed (3.0%) or intercropped (0.8%) are relatively scarce and silvoarable and agrosilvopastoral are poorly represented.
Regarding the spatial distribution of AF farms in the EU, Spain is the country with the largest surface area, followed by Greece and France. Also, Italy and Portugal have an important share of MF/AF systems. These five countries together represent approximately 67% of the total surface area occupied by MF/AF systems in EU-28. However, when expressing the surface area occupied by MF/AF systems as a percentage of UAA, Greece is the country with the highest proportion (37.2%). MF/AF systems occupy more than 20% of UAA in Cyprus and Portugal, and >12% in Sweden, Spain and Slovenia. At the other extreme are countries like Poland, Germany, Denmark, The Netherlands, United Kingdom and Ireland with ≤ 2.5% of their UAA occupied by MF/AF systems.
The analysis of woody linear features (WLF) evidenced abandoned hedgerows as the most abundant type, representing approximately 30%, followed by heath and shrubs and avenue trees. Almost a quarter of all considered land uses with WLF are found in France. The United Kingdom shares also a large proportion of

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the total number of points, followed by Spain and Germany. The most frequent land use type with WLF was arable crops, representing 59% of the total number of points, followed by grazed grasslands (28%). Given the abundance of wooded linear features in agricultural areas, they need to be taken into account as they constitute important elements which increase landscape diversity and biodiversity.

Data of MF/AF systems for the period from 2009 to 2018 evidenced marked changes: i) Grazed as well as intercropped permanent crops decreased by 42% and 33%, respectively; ii) silvopastoral land uses maintained stable; iii) the surface area occupied by home gardens increased by 20%. However, within this period remarkable variations were detected, with a strong increase of AF extent between 2009 and 2012, followed by a decrease from 2012 onwards. These changes were particularly notable in silvopastoral systems and were mainly related with changes of grazing activity. A more in-depth analysis revealed that data from 2009 were probably taken with different survey criteria than the ones carried out afterwards. Further research on these changes will be carried out within the AGROMIX project.

The physio-geographic characteristics of MF/AF systems in Europe were analysed, considering topography and climate key natural factors in agricultural activities. The spatial distribution of MF/AF data points and their relation with a variety of topography and climate variables revealed that they predominantly occur at lower elevations and at gentle slopes. These overall trends obscure some differences between the various MF/AF land use types. Particularly topography of silvopastoral is highly diverse. Furthermore, elevations and slope gradients of MF/AF systems are more frequent on steeper slopes than the complete European dataset, and on the contrary, are less frequent at very low elevations and very low slopes as compared with the EU as a whole.

In relation with climate characteristics, and considering MF/AF classes as a whole and grouped according to biogeographical regions, significant differences were detected. On the contrary, grouping the data by MF/AF classes did not result in significant differences which means that single classes do not show distinct climate characteristics, due to the fact that each class is distributed throughout Europe, but also because of an uneven distribution of sample sizes, with some land use classes having very few points. The report offers detailed information of the climatic and topographic characteristics of MF/AF data points.

Regarding climate change (CC), the most important projected changes for Europe which are based on the most recent report of the IPCC panel were analysed and the most important findings relevant for agricultural activities summarized in the present document. These include temperature rise and an increase of the frequency and magnitude of heatwaves. The frequency of cold spells and frost days are projected to decrease. Decreases in rainfall are projected in the Mediterranean region, particularly during summer, as well as an increase of drought frequency. In other regions of Europe, extreme rainfall and pluvial flooding are projected to increase. The observed decrease in glacial, permafrost and snow cover extent will continue.

The most important impacts of CC on MF/AF systems were described using the Mediterranean region as an example. These systems offer advantages regarding their resilience to CC as compared to more intensive land uses. Also, agroforestry systems when compared with forestry offer clear advantages, such as the reduction of wildfire risk and higher economic revenue. There are, however, still knowledge gaps which are subject of investigation in WP3 of the project.

The results produced in task 1.4 were integrated into a GIS data base. The latter also includes a whole set of other spatially distributed information, such as soils, tree density, population, etc. which will be used for upscaling of results generated in in AGROMIX.

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2 Expected impact

Deliverable 1.4 forms part of work package 1 (CONTEXT) which provides the theoretical background and characterisation of MF/AF systems. D1.4 consists of a report and GIS database on the impact of climate change on mixed farming and agroforestry systems in Europe. It includes a review of present-day MF/AF systems in the EU, including spatial distribution of the different land use combinations and recent changes. It also includes a physio-geographic characterisation of areas where these systems are practiced and a description of how these areas will be affected by climate change. All data and results are included in a geographical information system (GIS database).

D1.4 produces impacts on studies carried out within the AGROMIX project. It contributes to WP3 with a large spatially distributed data set which will be used for extrapolating results obtained from case studies, as well as from modelling, to the regional and European scale. Task 1.4 did also prepare land use/land cover data for a case study on England in WP6.

It is foreseen that project results will have a scientific impact as results will be published in scientific journals, one on recent changes in agroforestry in Europe and another one dealing with the importance of woody landscape features in agricultural areas of the European Union.

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3 Introduction

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 (https://agromixproject.eu/).

This report presents the findings of AGROMIX's Work Package One (WP1) Task 1.4 and constitutes a review of present-day mixed farming and agroforestry systems in Europe. It aims at explaining the distribution of MF/AF systems in Europe and its relation to environmental factors. Furthermore, it will describe how these systems will be affected by climate change. In addition, although not originally included in the objectives of task 1.4, is an analysis of the detected changes in the distribution of MF/AF systems between 2009 and 2018. The present report of WP1 was preceded by three reports corresponding with the deliverables of tasks 1.1 to 1.3:

- Handbook of resilience and working definitions. It reflects on relevant concepts related with mixed farming and agroforestry systems, highlighting the important and pointing to gaps, and presents the definition of relevant terms.
- Climate smart agriculture: ecosystem services in mixed farming and agroforestry systems. It includes an evaluation of ecosystem services and disservices present in MF and AF systems for climate-smart agriculture. The survey was carried out in the pilot farms of AGROMIX and other collaborating farms and provided insight into the perception of farmers about ecosystem services and disservices.
- Farm-level indicators for resilience to climate change stressors. This report proposes relevant indicators for determining resilience of MF/AF farms, including the methodology for their determination.

The AGROMIX project 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, based on a prior definition of Burgess et al. (2015). Similarly, AGROMIX considers mixed farming as the practice of deliberately integrating crop and livestock production to benefit from the resulting ecological and economic interactions (Püttsepp et al., 2020). The term mixed farming is used in the sense of "integrated crop livestock systems", which is commonly used in North and South America. It, hence, differs from the definition used in the farm accountancy data network (FADN) framework, which defines a mixed farm as one where the "standard output" of the dominant crop or livestock enterprise must be no more than two thirds of the total output of the farm.

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3.1 Objectives

The objectives of task 1.4 are as follows:

- Review of MF/AF systems in Europe, covering aspects of multifunctional activities, multi-products, land use diversification, etc., including an estimation of the extension of MF/AF systems by regions and climatic zones (spatial distribution).
- Analysis of recent changes in MF/AF systems based on LUCAS data.
- Physio-geographic characterisation of areas where these systems are practiced, mainly based on climate and geomorphological context.
- A review of climate change in Europe and how these areas will be affected, emphasizing the risks for farm management in the different regions.
- Creation of a GIS database which will be used for upscaling carried out in WP3 task 3.3.

3.2 Document structure

This report is structured in ten main chapters. This first Chapter provides an overview of the context and the aims of the report.

Chapter 1 presents an executive summary.

Chapter 2 includes the main impacts of deliverable 1.4.

Chapter 3 is an introduction of task 1.4 and the present report.

Chapter 4 provides a summary of current knowledge on the extent and spatial distribution of MF/AF in Europe.

Chapter 5 details the methodology used in the analysis on the extent, spatial distribution and recent changes of MF/AF in the European Union, including a description of the LUCAS surveys, the classification of MF/AF systems, and approaches to the data analysis.

Chapter 6 presents the results from a geographical perspective, characterization of the extent and spatial distribution of MF/AF systems in Europe at national level and across biogeographical regions. It also analyses temporal changes of MF/AF systems in Europe between 2009 and 2018.

Chapter 7 describes MF/AF in the European Union in the context of physical-environmental factors, focussing on topographical and climate characteristics of these systems.

Chapter 8 provides an overview of predicted climate change in Europe and its effects on MF/AF systems.

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Chapter 9 details the creation of a spatial database, integrated into a geographical information system, which will be used for upscaling of results obtained in AGROMIX WP3. This database includes, amongst others, information on climate, topography, land use, land cover, soils, and tree density.

Chapter 10 presents a summary of the main findings obtained in task 1.4, together with some critical remarks on the results obtained. It also presents suggestions as how the insights obtained on MF/AF systems in Europe can be taken forward, both within the AGROMIX project and beyond.

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4 Current knowledge on the extend and spatial distribution of MF/AF in Europe

The review of MF/AF systems in Europe carried out in the present task builds on the work of Den Herder et al. (2015; 2017). In the framework of the European project AGFORWARD, these authors used the LUCAS database from survey year 2012 to characterize agroforestry systems in the EU. According their estimates the total area under agroforestry in the European Union (27 member states) was about 15.4 million ha which is equivalent to about 3.6% of the territorial area or 8.8% of the utilised agricultural area (UAA) (Den Herder et al., 2017). They differentiated three main categories of agroforestry systems: livestock agroforestry, high value tree agroforestry and arable agroforestry, covering each 15.1, 1.1 and 0.3 million hectares, respectively. High value trees are equivalent to permanent crops. The largest extensions of AF systems are found in Spain, France, Greece, Italy and Portugal, highlighting the importance of these land use systems in Mediterranean countries (den Herder et al., 2017). If the extent of agroforestry is expressed as a proportion of UAA highest percentages were reported for Cyprus, Portugal and Greece with values in excess of 40% (den Herder et al., 2017).

Mosquera-Losada et al. (2019) carried out an analysis using LUCAS data, considering also home gardens and hedgerows and riparian buffer strips. Home gardens, also called kitchen gardens, are gardens or small orchards where crops are planted heterogeneously and mainly for own consumption. They are commonly situated in urban or suburban areas.

Forest farming was not evaluated in the LUCAS surveys, i.e. those including economic activities apart from forestry. Mosquera-Losada et al. (2019) presented a summary of a review carried out by the 2015 Ministerial Conference on the Protection of Forests in Europe about the status of the production of forest farming (non-wood forest production). These authors highlight the importance of food (berries, mushrooms, etc.), ornamental plant products, wild meat and honey in forest farming.

An example of agroforestry activities not taken into account in the LUCAS surveys is reindeer husbandry, of great economic and cultural importance for many indigenous people in Scandinavia. Jensletten and Klokov (2002) quoted 227.000 reindeer grazing on 160.000 km2, or about 34% of Sweden, and 186.000 reindeer grazing on 114.000 km2 in Finland, or 33% of its territory for the turn of the 21st century. Reindeers graze forests in the winter months consuming mainly lichens. This means that the surface areas mentioned above include also large non-forest areas and that these figures can not be used as an approximation of AF, but it illustrates on their importance.

A comparison with the results obtained in the present study and the ones published by den Herder et al. (2019), Mosquera-Losada et al. (2019), other authors and is included in the Discussion section.

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Mixed farms are defined in AGROMIX as those where temporary crops are cultivated in combination with livestock rearing. LUCAS data allows only the estimation of the surface area of grazed arable crops, i.e. the combination of temporary crops and grazing livestock, but does not include other mixed systems, for example where cropland is combined with stabled domestic animals. This means that the study carried out within task 1.4 of the project dealing with the extent and spatial distribution of MF/AF in Europe will present a clear limitation as areas with MF cannot realistically be quantified.

In order to delve into this topic a literature review as well as a search on data availability from different sources was carried out. Two projects, namely the CanTogether project (Leterme et al., 2016) and the EIP-AGRI Focus Group on Mixed Farming Systems (2017) offer some information on the subject. However, the reports and publications delivered by these projects do only offer some information based on farm type data extracted from Eurostat. No scientific articles dealing with the spatial distribution of MF in Europe were found neither. For this reason, Eurostat information on farm types was analysed, being the most recent data from 2013.

MF systems are very diverse and Leterme et al. (2016) in their final report of the CanTogether (Crops and livestock together) project differentiated four principal types, based on the interaction between the three components of MF systems: crops, grasslands and animals and the way these components interact: ICL0: coexistence, ICL1: complementarity, ICL2: on-farm synergy, ICL3: territorial synergy, with ICL meaning integrated crop livestock. Moraine et al. (2014, p. 1206) defines these four types in the following way:

“Type 1: exchange of materials (e.g. grain, forage, straw, waste as organic fertiliser) between specialised farms, regulated by the market, in a rationale of ‘coexistence’.
Type 2: exchange of materials between spheres in a rationale of ‘complementarity’ at the farm if not territorial level. Crop systems are designed to meet the needs of livestock enterprises (need for concentrates, raw forages and straw) and livestock waste to fertilise arable plots.
Type 3: increased temporal and spatial interaction among the three spheres in a rationale of ‘farm-level synergy’: stubble grazing, temporary grasslands in rotations, intercropped forages. A high level of diversity in farm components is targeted to enhance regulating services.
Type 4: increased temporal and spatial interaction among the three spheres in a rationale of ‘territory-level synergy’: organisation optimises resource allocations, knowledge sharing and cooperation, including work.”

Albeit recognizing this diversity, data availability hampers a geographical analysis. Eurostat offers data on mixed farming differentiating 5 types which are included in Table 1, together with the total surface extent and their proportion with respect to the utilized agricultural area (UAA). Following the definition of MF used in AGROMIX only the two farm types ‘Field crops combined with grazing livestock’ and ‘various crops combined with granivore livestock’ were considered as such. Not included were farms with mixed cropping or mixed livestock. MF occupies 198,927 km^2, corresponding to 11.2% of UAA being cropland with grazing livestock the most extensive with 130,947 km^2 (7.3% UAA).

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Table 1. Extent of different mixed farming types in EU-28 in 2013 and their proportion with respect to UAA (Eurostat).

Farm type	Extent (km²)	% UAA
Mixed cropping	48,119	2.7
Mixed livestock, grazing	2,286	1.5
Mixed livestock, granivores	13,044	0.7
Field crops-grazing livestock	130,947	7.3
Various crops and livestock	67,979	3.8
Total	**262,375**	**16.1**

The extent of the two types of MF in EU-28 is presented in Table 2 and Figure 1. France is the country with the largest surface area of MF with 35,230 km^2, followed by Germany and Poland which each have slightly more than 30,000 km^2 of MF.

The share of MF with respect to UAA is shown in Figure 2. Czechia is the country with the largest share of MF, with 34.1%. Also, high percentages were found in Slovakia (26.5%) and Poland (21.0%). Values between 15% and 20% were observed in Lithuania, Germany, Croatia and Latvia.

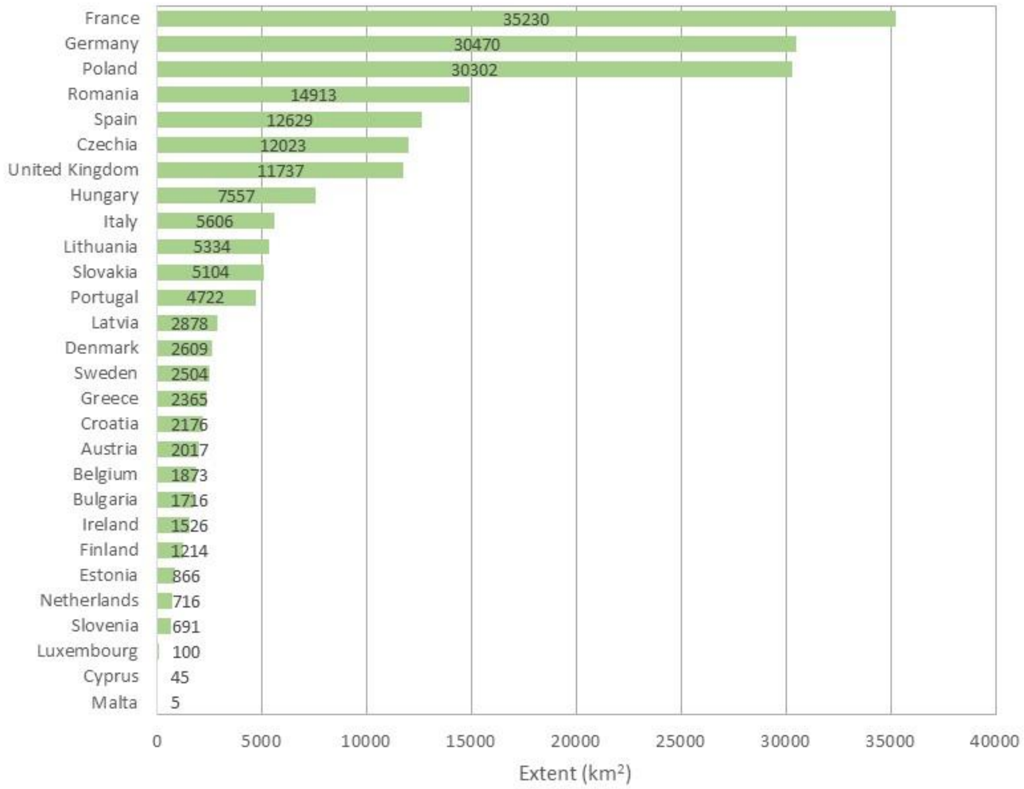

Figure 1. Extent of MF farms in EU-28 (elaborated from Eurostat data, 2013).

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Table 2. Extent of field crops combined with grazing livestock and various crops combined with granivore livestock in the European Union, as well as their share of UAA in 2013 (data from Eurostat).

Country	UAA_2013 (km^2)	Field crops-grazing livestock (km^2)	Various crops and livestock (km^2)	Field crops-grazing livestock (% UAA)	Various crops and livestock (% UAA)
Austria	28624	964	1053	3.4	3.7
Belgium	13386	1486	388	11.1	2.9
Bulgaria	49951	1210	506	2.4	1.0
Croatia	13008	975	1201	7.5	9.2
Cyprus	1071	12	33	1.1	3.1
Czechia	35210	10144	1879	28.8	5.3
Denmark	26278	1242	1366	4.7	5.2
Estonia	9659	631	235	6.5	2.4
Finland	22586	588	626	2.6	2.8
France	291460	29995	5235	10.3	1.8
Germany	166996	21639	8831	13.0	5.3
Greece	52130	694	1671	1.3	3.2
Hungary	53400	4602	2955	8.6	5.5
Ireland	44776	1472	54	3.3	0.1
Italy	124260	2820	2786	2.3	2.2
Latvia	18777	1990	888	10.6	4.7
Lithuania	28914	3843	1491	13.3	5.2
Luxembourg	1310	83	17	6.3	1.3
Malta	117	1	4	0.7	3.3
Netherlands	18476	380	336	2.1	1.8
Poland	144099	15615	14688	10.8	10.2
Portugal	37182	1374	3348	3.7	9.0
Romania	139046	4461	10453	3.2	7.5
Slovakia	19285	4354	750	22.6	3.9
Slovenia	4789	169	522	3.5	10.9
Spain	234946	8498	4131	3.6	1.8
Sweden	30361	1826	678	6.0	2.2
United Kingdom	172590	9881	1855	5.7	1.1
Total	**1782688**	**130947**	**67979**	**7.3**	**3.8**

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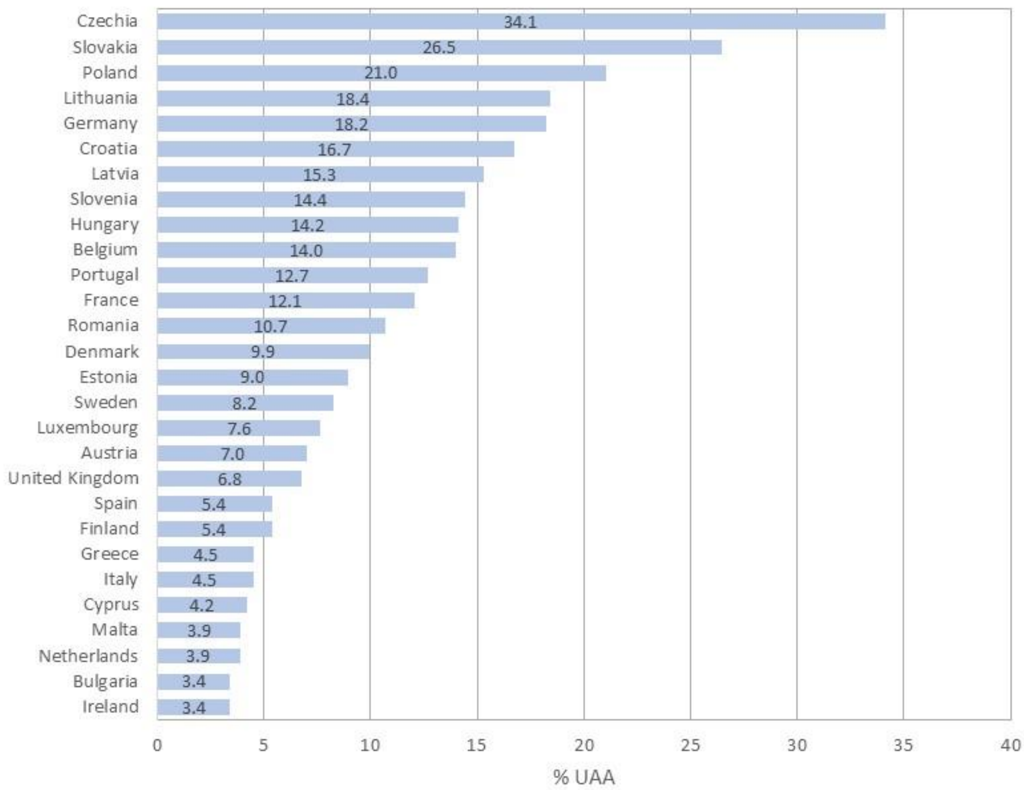

Figure 2. MF as a percentage of UAA in the EU in 2013 (Data from Eurostat). MF includes field crops combined with grazing livestock and various crops combined with granivore livestock

EUROSTAT also offers farm type data for 2013 at the NUTS-2 scale, except for Germany, where only NUTS-1 data are available, resulting in a total of 249 regions. This higher spatial resolution permits to depict clearer the distribution of MF within the European Union (Figure 3). The average share of MF at this regional scale is 10.4% of UAA. However, the median value is only 7.8%, i.e. half of these regions have a MF share lower than this value. As shown in figure 3, some regions have particularly high shares (> 30%). These are most regions of Czechia, Západné Slovensko in Slovakia, several regions in eastern Germany (Thüringen, Sachsen, Berlin, Brandenburg) and Lorraine in France. Only one fifth of all regions have shares in excess of 16.7% and, at the other extreme of the frequency distribution, one fifth of the regions have less than 3.5% of their UAA as MF.

Regarding the temporal changes of MF in Europe, Leterme et al. (2016) presented some interesting information which is summarized as follows: Due to a process of specialization in the farm sector, mixed farming is decreasing. In 2010, 47% of farms in the EU-28 were specialised in cropping, 27% in livestock and 24% in mixed farming. Agrosynergie (2013) cited in Leterme et al. (2016) reported that the number of farms in all sectors with the lowest degree of specialisation has decreased significantly in the EU between 2004 and 2009, with 34% of mixed crop-livestock moving to more specialized sectors. For the same period, the number of more specialized farms (specialist field or permanent crops or specialist grazing livestock) has increased by 5%.

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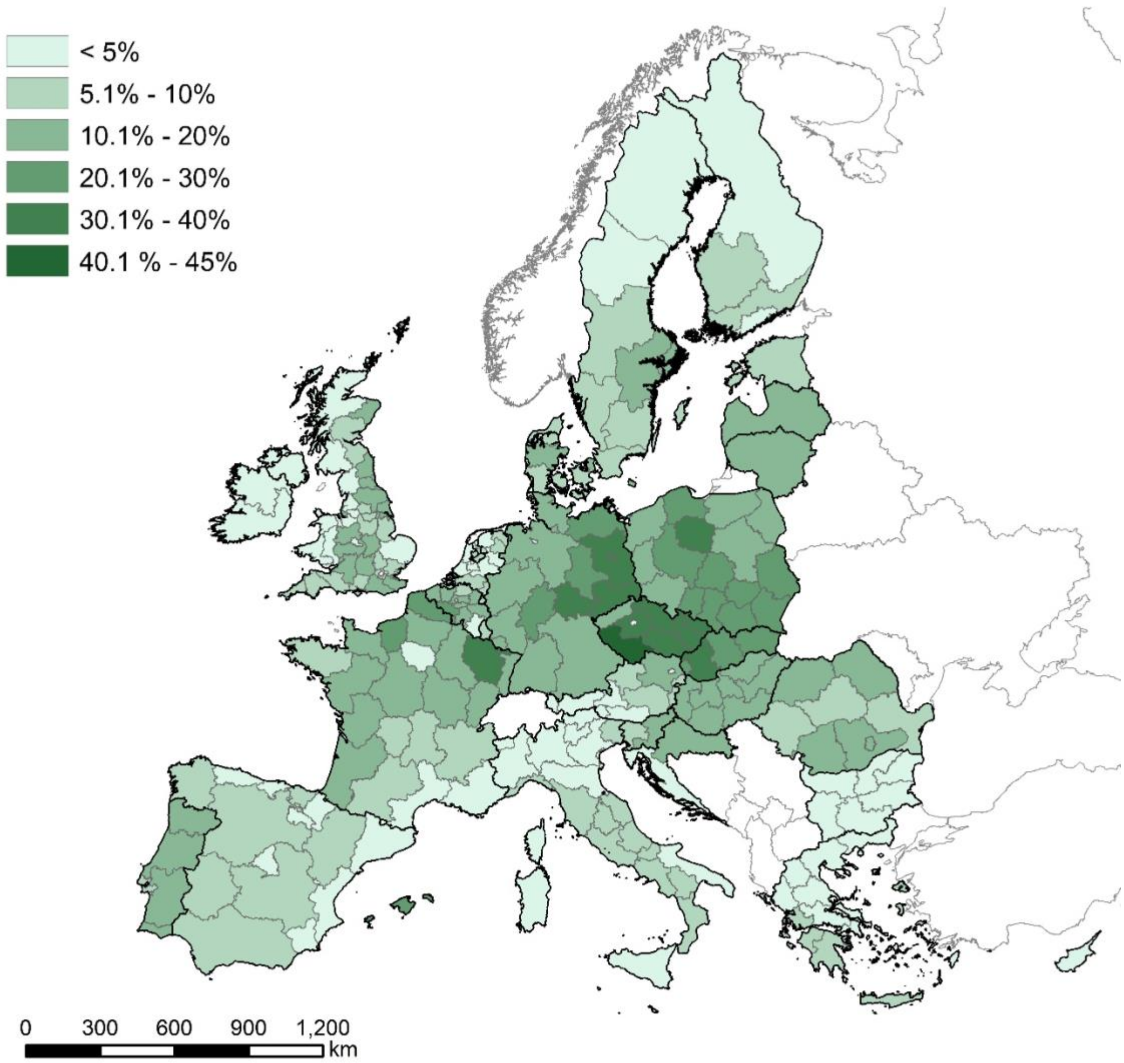

Figure 3. Share of UAA managed in MF in the EU at NUTS-2 scale. For Germany only data at NUTS-1 available (Eurostat, EU-28, 2013).

In order to detect changes of MF in Europe, data from EUROSTAT for years 2005, 2007, 2010 and 2013 were analysed. Table 3 presents the surface extent of MF, i.e. the sum of the two classes: field crops combined with grazing livestock and various crops and livestock for the different European member states, except Croatia. The total extent in EU-27 decreased from 233,298 km^2 in 2005 to 196,751 km^2 in 2013, which represents a reduction of 15.7% in only 8 years. Most countries experienced decreases, some of more than 40%, such as Greece (-49.7%) and Romania (-46.7%). Bulgaria and Lithuania also showed strong decreases with -36.9% and -30.2%, respectively. Only few countries experienced increases, such as Austria (14.9%), Finland (13.1%) and Slovenia (7.4%).

Interestingly, the two types of MF did not show the same tendency, as can be depicted from Figure 4. Various crops and livestock combined registered a strong decrease from 98,233 km^2 to 66,779 km^2 which corresponds

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to -32.0%. Contrary, field crops combined with grazing livestock decreased only slightly (-3.8%), registering an increase from 2010 to 2013 (Figure 4). Annex 1A and 1B includes the data corresponding to each MF type for individual EU countries.

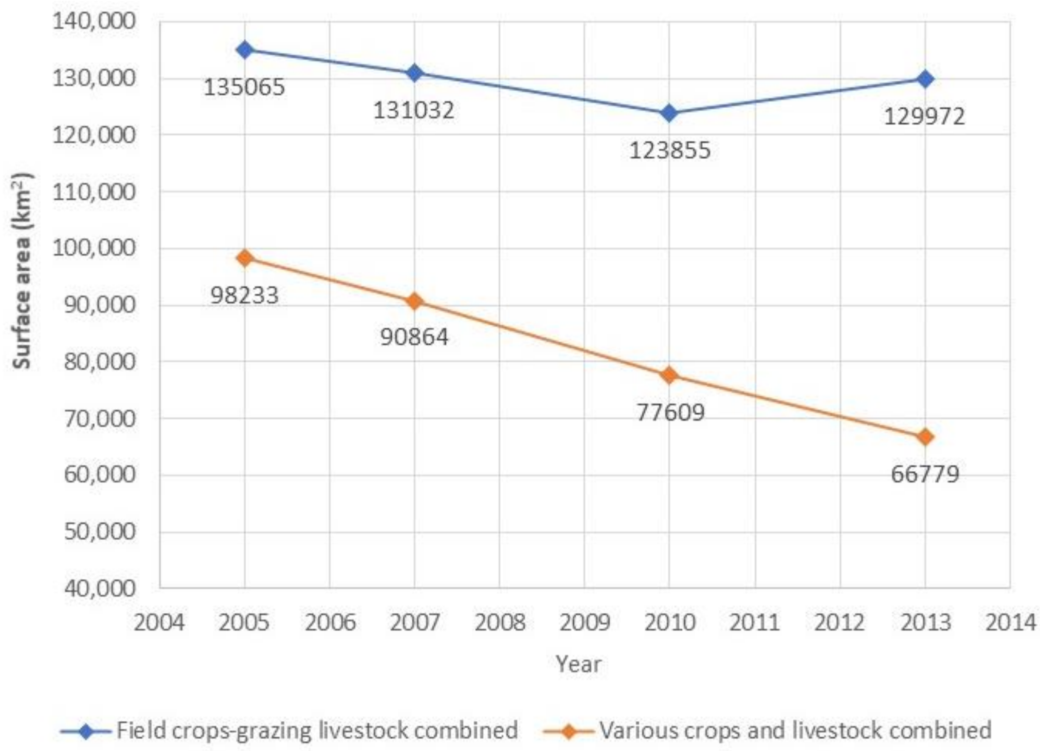

Figure 4. Changes of surface extent (km^2) for the two types of MF from 2005 until 2013 in EU-27 (without Croatia) (analysis based on data from EUROSTAT).

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Table 3. Surface extent (km²) of MF in EU-27 for years 2005, 2007, 2010 and 2013, as well as the difference and percentage difference observed between 2005 and 2013 (analysis based on data from EUROSTAT). Countries with an increase of MF are highlighted in grey and those with strong decreases in yellow.

Country	2005	2007	2010	2013	Difference	%difference
Austria	1756	1668	1656	2017	261	14.9
Belgium	2234	2206	2076	1873	-361	-16.2
Bulgaria	2718	3172	2011	1716	-1002	-36.9
Cyprus	77	76	55	45	-32	-41.7
Czechia	14446	13809	12702	12023	-2423	-16.8
Denmark	3251	3140	3092	2609	-642	-19.8
Estonia	923	815	867	866	-57	-6.2
Finland	1073	1104	1146	1214	141	13.1
France	33848	33349	33219	35230	1382	4.1
Germany	35139	34245	29883	30470	-4669	-13.3
Greece	4701	4459	3383	2365	-2336	-49.7
Hungary	8880	7814	7895	7557	-1323	-14.9
Ireland	1713	1291	1376	1526	-187	-10.9
Italy	6907	6483	5460	5606	-1301	-18.8
Latvia	3884	3446	2630	2878	-1006	-25.9
Lithuania	7646	6401	5352	5334	-2311	-30.2
Luxembourg	94	94	98	100	7	6.9
Malta	7	4	5	5	-2	-29.2
Netherlands	911	846	803	716	-194	-21.3
Poland	33397	32351	33972	30302	-3095	-9.3
Portugal	5210	4396	5003	4722	-487	-9.4
Romania	28001	26084	15864	14913	-13088	-46.7
Slovakia	6542	6178	5244	5104	-1438	-22.0
Slovenia	643	623	664	691	47	7.4
Spain	14094	13341	13230	12629	-1464	-10.4
Sweden	2931	2597	2689	2504	-427	-14.6
United Kingdom	12276	11905	11090	11737	-539	-4.4
Total	**233298**	**221896**	**201464**	**196751**	**-36547**	**-15.7**

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5 Methodology

5.1 The LUCAS surveys

LUCAS stands for Land Use/Cover Area Frame Survey and its data offer a comprehensive and comparable overview on the state and the dynamics of land use and cover in the European Union (Ballin et al., 2018). The Eurostat's LUCAS survey provides harmonised statistics on land use and land cover across the European Union. Land use identifies the socio-economic usage of a given land, such as agriculture, commerce, industry, etc. Meanwhile, land cover refers to the bio-physical coverage of the land: crops, woodland, buildings, roads, etc. It provides unique, in-situ information by surveys carried out since 2006 every 3 years. The latest LUCAS survey, covering all the 28 European Union (EU) countries, took place in 2018. In the following we keep speaking of EU-28, although United Kingdom left de EU, though this was after the last LUCAS survey. EU-28 is understood here as EU27+UK.

LUCAS is carried out by direct observations of surveyors in a small area in the field centred on a selected point. The survey is a multipurpose in-situ platform. The core survey includes the nature of land cover (arable, grassland, artificial, water, etc.), its use (industry, agriculture, transport, housing, etc.), land management (grazing, ploughing, etc.), as well as environmental parameters associated to the single surveyed points and a set of pictures taken on the point and in the cardinal directions (Ballin et al., 2018).

Although the first survey was carried out in 2006, the number of sample points was small, so that the 2009 survey was used, which saw a marked expansion in terms of the geographical coverage (23 Member States) and higher point density. The last survey is from 2018 and includes all EU-28 member states. More information on the methodology is provided in the following chapter and can also be obtained in Eurostat (2019).

This section describes how LUCAS data is taken, includes information on the type of data available and the sample size (data points) of the EU countries for the different surveys, carried out every 3. LUCAS is based on a two phases sample survey. In the first phase points are systematically sampled in a regular grid with a spacing of 2 km covering the whole territory of the EU. This survey contains around 1.1 million different points and can be called the Master or Frame. Each point of the first phase sample is photo-interpreted and assigned a pre-defined land cover class (Eurostat, 2019).

From the first phase sample, a second phase sample of points is drawn randomly and proportionally with respect to the assigned land cover class (more detail on the sampling procedure in Ballin et al., 2018). These points are the ones which are visited in the field and investigated. In the field survey the LUCAS observers visit the points annotating land cover, land use and other environmental parameters they find on the ground. The land cover and land use are noted according to a harmonised classification. The surveyor also collects information relating to the percentage of land cover within a specific window of observation, the area size,

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the width of any specific feature, the height of any trees, as well as information on land and water management (for example, grazing or irrigation) (Eurostat, 2019). Those points which could not be visited for any reason, e.g. problems of accessibility, are evaluated using photo interpretation (PI). Regarding the geographical location, in the first place the coordinates of the theoretical location are established, once in the field the coordinates of the real sampling point are measured with a GPS. Those points which could not be visited and analysed by PI are assigned the theoretical coordinates. The LUCAS database includes both coordinates, the real and the theoretical ones. Figure 5 illustrates the field survey.

The existence of livestock grazing is classified as land management and the surveyor has to observe whether the plot to which the point belongs shows signs of grazing. There should be visible signs for grazing management: pastures, where cattle are out at feed and/or infrastructure is seen (fences, stables, drinking troughs) and/or dung or cattle trampling can be observed (Eurostat, 2013). Areas grazed during summer (transhumance) are also considered. If the land cover is suitable for grazing but no signs of grazing are visible, it is marked "no signs of grazing" (Eurostat, 2013). There is a further rule, not mentioned in Eurostat (2013), but included in Eurostat (2018) that states: "if there is nothing to be grazed select 'Grazing not relevant'. This means that a field might have been grazed, but is not so at the moment of the visit as there is no pasture available.

At each point information on land cover along a 250 m transect in an East direction is also taken (Figure 5). See chapter 2.3 for more information.

The survey points are integrated into a GIS using their real coordinates if available or the theoretical in case of PI, together with variables including altitude, land cover, land use and management and transect information.

Surveys were carried out in 3-year intervals. In the present study only data from survey 2009 onwards were used because the number of sampling points from previous surveys were considered too small. Hence, we could use four surveys with the following number of points:

2009: 234,484
2012: 270,152
2015: 338,725
2018: 337,854

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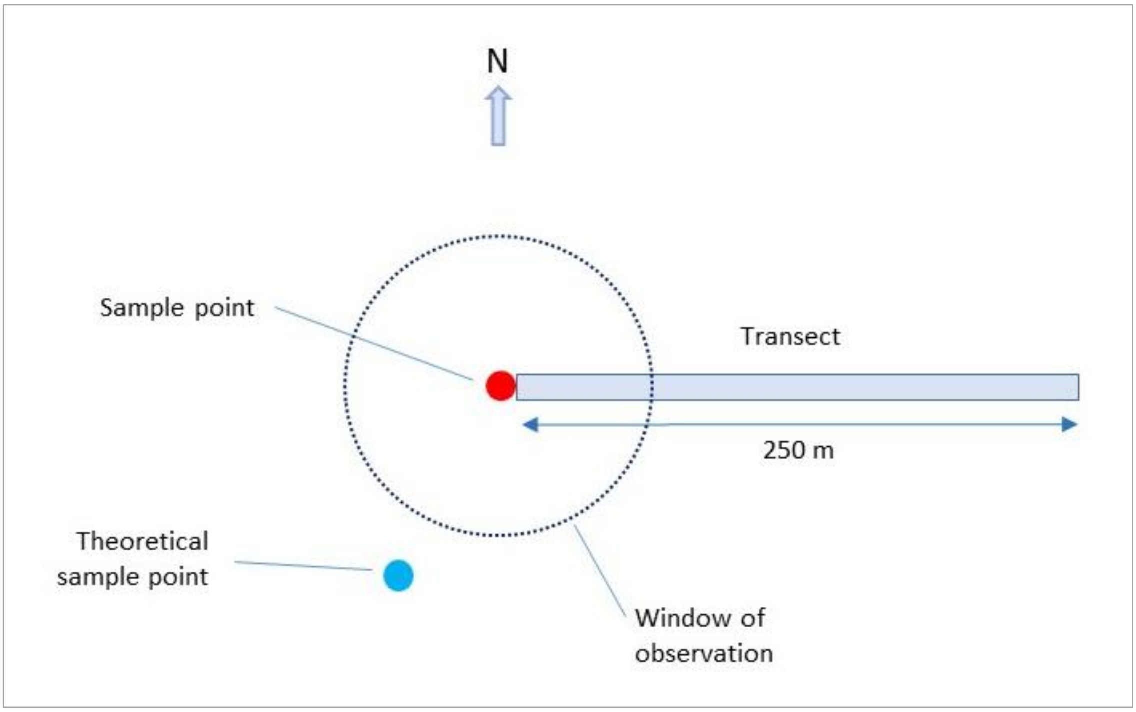

Figure 5. Scheme illustrating the LUCAS field survey (the window of observation has not a fixed size, but depends on the size of the field or other variables).

Table 4 presents the number of sample points for each EU member state and for the different survey years. Between 2009 and 2015 the number of sample points increased from 234,484 to 338,725, related mainly with an increment of points per country (78,269), but also with the inclusion of new countries in the EU (25,972 points: Bulgaria, Cyprus, Croatia, Malta, Romania). Between 2015 and 2018 the total number of points remained almost unchanged, although some countries registered increases and others decreases. For example, the number of points of the Netherlands almost doubled, meanwhile Portugal registered a decrease (Table 4).

LUCAS (EUROSTAT, 2015) uses a double land cover classification system when there are multiple layers of land covers, which is often the case for MF/AF systems, where in addition to a tree layer there may also be a secondary layer composed of crops or grasses. In LUCAS the presence of a tree layer is always marked as the primary land cover (LC1), and the secondary land cover (LC2) can be composed of other types of covers, such as crops or shrubs. The combination of the two land covers is used for classification of mixed farming and agroforestry lands. The land covers relevant for this study are presented in Table 5 and Annex 2 includes the complete table.

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Table 4. Number of sample points of each EU member state and each survey year.

COUNTRY	Country code	2009 (EU23)	2012 (EU27)	2015 (EU-28)	2018 (EU-28)
Austria	AT	4961	6469	8839	8840
Belgium	BE	1804	2446	2899	3659
Bulgaria	BG		6641	7677	7678
Croatia	HR			3532	4239
Cyprus	CY		1442	1726	2313
Czechia	CZ	4662	5514	5712	5713
Denmark	DK	2540	3442	3665	3703
Estonia	EE	2663	2200	2637	2665
Finland	FI	19895	13476	16116	16182
France	FR	32318	38324	48188	48215
Germany	DE	21113	24939	26598	26777
Greece	EL	7758	7821	12521	12622
Hungary	HU	5513	4637	5169	5514
Ireland	IE	4164	3484	4907	4975
Italy	IT	17790	20985	28693	28294
Latvia	LV	3825	4420	5374	5376
Lithuania	LT	3860	3889	4505	4584
Luxembourg	LU	152	213	251	340
Malta	MT		79	79	79
Netherlands	NL	2449	2237	2521	5011
Poland	PL	18487	21797	22980	23086
Portugal	PT	5423	7332	9006	7168
Romania	RO		14278	16720	16725
Slovakia	SK	2898	2455	2755	2898
Slovenia	SI	1203	1621	1923	1922
Spain	ES	29912	35377	50281	45314
Sweden	SE	26656	22420	26648	26709
United Kingdom	UK	14438	12214	16803	17253
Total		**234484**	**270152**	**338725**	**337854**

Another important variable in the LUCAS database for identifying MF/AF systems is land use, the most relevant ones are shown in Table 6. The complete information can be found in Annex 3. It includes information on whether the point has agricultural, forestry or other land uses. Kitchen gardens are also identified as a separate land use (Table 6). They are also called home gardens and refer to gardens or small orchards where crops are planted heterogeneously and are mainly dedicated to own consumption. These areas are mostly fenced and situated in residential areas or as allotment gardens.

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Table 5. LUCAS land covers considered in MF/AF classes and corresponding codes.

CODE	DESCRIPTION
B00 CROPLAND	
B10 Cereals	
B11	Common wheat
B12	Durum wheat
B13	Barley
B14	Rye
B15	Oats
B16	Maize
B17	Rice
B18	Triticale
B19	Other cereals
B20 Root crops	
B21	Potatoes
B22	Sugar beet
B23	Other root crops
B30 Non-permanent industrial crop	
B31	Sunflower
B32	Rape and turnip rape
B33	Soya
B34	Cotton
B35	Other fibre and oleaginous crops
B36	Tobacco
B37	Other non-permanent industrial crops
B40 Dry pulses, vegetables and flowers	
B41	Dry pulses
B42	Tomatoes
B43	Other fresh vegetables
B44	Floriculture and ornamental plants
B45	Strawberries
B50 Fodder crops	
B51	Clovers
B52	Lucerne
B53	Other leguminous and mixtures for fodder
B54	Mixed cereals for fodder
B55	Temporary grasslands
B70 Permanent crops: Fruit trees	
B71	Apple fruit
B72	Pear fruit
B73	Cherry fruit
B74	Nuts trees
B75	Other fruit trees and berries
B76	Oranges
B77	Other citrus fruit
B80 Other permanent crops	
B81	Olive groves
B82	Vineyards
B83	Nurseries
B84	Permanent industrial crops
Bx1	Arable land (only PI)
Bx2	Permanent crops (only PI)
C00 WOODLAND	
C10	Broadleaved woodland

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C20 Coniferous woodland	
C21	Spruce dominated coniferous woodland
C22	Pine dominated coniferous woodland
C23	Other coniferous woodland
C30 Mixed woodland	
C31	Spruce dominated mixed woodland
C32	Pine dominated mixed woodland
C33	Other mixed woodland
D00 SHRUBLAND	
D10	Shrubland with sparse tree cover
D20	Shrubland without tree cover
E00 GRASSLAND	
E10	Grassland with sparse tree/shrub cover

Table 6. Summary of LUCAS land use codes relevant in this study. Grazing, considered as land management is included here.

CODE	DESCRIPTION
GRAZING	1 = grazing areas; 2 = no grazing areas; 8 = not relevant
U100	**PRIMARY SECTOR**
U110	AGRICULTURE
U111	Agriculture (excluding fallow land and kitchen gardens)
U112	Fallow land
U113	Kitchen garden
U120	FORESTRY
U200	**SECONDARY SECTOR**
U210	ENERGY PRODUCTION
U220	INDUSTRY AND MANUFACTURING
U300	**TERTIARY SECTOR, TRANSPORT, UTILITIES AND RESIDENTIAL**
U310	TRANSPORT, COMMUNICATION NETWORKS, STORAGE, PROTECTION WORKS
U320	WATER AND WASTE TREATMENT
U330	CONSTRUCTION
U340	COMMERCE, FINANCIAL, PROFESSIONAL AND INFORMATION SERVICES
U350	COMMUNITY SERVICES
U360	RECREATION, LEISURE, SPORT
U370	RESIDENTIAL
U400	**UNUSED AND ABANDONED AREAS**
U410	ABANDONED AREAS
U420	SEMI-NATURAL AND NATURAL AREAS NOT IN USE

Also important is the information which can be obtained about livestock raising, considered land management in the LUCAS survey. The surveyors in their field visit observes if there are signs of grazing livestock allowing to recognize the existence of a pastoral land use system (included in table 3).

The selection of certain combinations of primary and secondary land covers, as well as information on land use and management, enables the identification of MF/AF systems points and their classification which is described in the following chapter.

Very important for our work was the harmonisation of the LUCAS data from 2006 to 2018, carried out by d'Andrimont et al. (2020) which was used in the present study. The complete harmonised database can be downloaded freely and the process is described by the authors in the attached publication.

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5.2 Classification of mixed farming and agroforestry

MF/AF systems were stratified following criteria presented in Table 7 and illustrated in Figure 6. In this way, agroforestry systems were classified in six classes:

- grazed permanent crops
- intercropped permanent crops
- silvoarable
- silvopastoral
- agrosilvopastoral
- homegardens

Mixed farming systems were identified as grazed arable (temporary) crops and represent only one class. It is important to note that the only type of mixed farming which can be identified in LUCAS is grazed arable crops, i.e. cropland where also grazing has been observed. This means that other forms of MF cannot be identified and are, hence, not considered in the following analysis.

Furthermore, other agricultural areas and which have not been considered so far (those included in Table 7) and which have linear woody features (LWF), were treated separately, identifying three groups: grazed grasslands, croplands (temporary crops) and permanent crops with LWF (Figure 6). Chapter 5.3 describes the analysis of this type of MF/AF system.

This classification resulted in 9 principal MF/AF classes (Figure 6). Furthermore, the LUCAS database includes detailed information on land covers which allows a more in-depth analysis of MF/AF systems to be conducted, such as the species of permanent or temporary crops, woodland type, etc., and also on the type of linear features.

In practice, the complete dataset of one LUCAS survey year was downloaded into an Excel sheet, each sample point represents a case (row) and the variables are presented in columns. The latter includes point number, EU country, country code, geographical location (x, y coordinates), land cover 1 and land cover 2, land use, land management, information on linear features, amongst others. The following examples illustrate the definition of a MF/AF system with the help of tables 4-6:

- L1: broadleaved woodland (C10) + Management: signs of grazing = *Silvopastoral*
- L1: pine dominated coniferous woodland (C22) + L2: Common wheat (B11) = *Silvoarable*
- L1: barley (B13) + Management: signs of grazing = *Grazed arable crops* (mixed farming)
- L1: olive groves (B81) + L2: common wheat (B11) = *Intercropped permanent crops*

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Table 7. Criteria used to identify agroforestry (AF) and mixed farming (MF) systems classes. LC1 = primary land cover; LC2 = secondary land cover; Undetermined (U) means that any combination is possible, but not relevant for classification. LU = land use.

System	Class	LC1	LC1 Code	LC2	LC2 Code	Grazing	LU1
AF	Grazed permanent crops	Permanent crops	B71-B83, B84k, B84m, Bx2	U	U	Yes	
	Intercropped permanent crops	Permanent crops	B71-B83, B84k, B84m, Bx2	Arable crops	B11 -B54, Bx2	No	
	Silvoarable	Woodlands; Shrublands	C10-C33, D10-D20, E10	Arable crops	B11-B54, Bx2	No	
	Silvopastoral	Woodlands; Shrublands; Grasslands with sparse tree cover.	C10-C33, D10-D20, E10	Permanent crops; Woodlands, Shrublands; Grasslands; Not relevant	B71- B83, B84k, Bx2, D10-D20, E10-E30, 8	Yes	
	Agrosilvo-pastoral	Woodlands; Shrublands; Grasslands with sparse tree cover.	C10-C33, D10-D20, E10	Arable crops	B11-B54, Bx2	Yes	
	Home gardens	U	U	U	U		113
MF	Grazed arable crops	Arable crops	B11-B54, Bx2	U		Yes	

<u>Home gardens</u> or kitchen gardens represent a land use (not a combination of land covers; code 113), identified as gardens or small orchards where the crops are planted heterogeneously and mainly for own consumption. These areas are mostly fenced (by metal fences or hedges) and mostly situated in residential areas or as allotment gardens. This class combines different land covers like temporary crops, permanent crops and, sometimes, shrublands and grasslands. Grazing is not a relevant land management in this type of systems, though livestock may be present. As kitchen gardens constitute a land use, their land covers are also included in LUCAS, as well as grazing if observed. This is important to explain because some kitchen gardens overlap with points classified as MF/AF systems. Therefore, in order to avoid duplicities, only those LUCAS points not classified as MF/AF systems, but classified as kitchen gardens, were considered as such.

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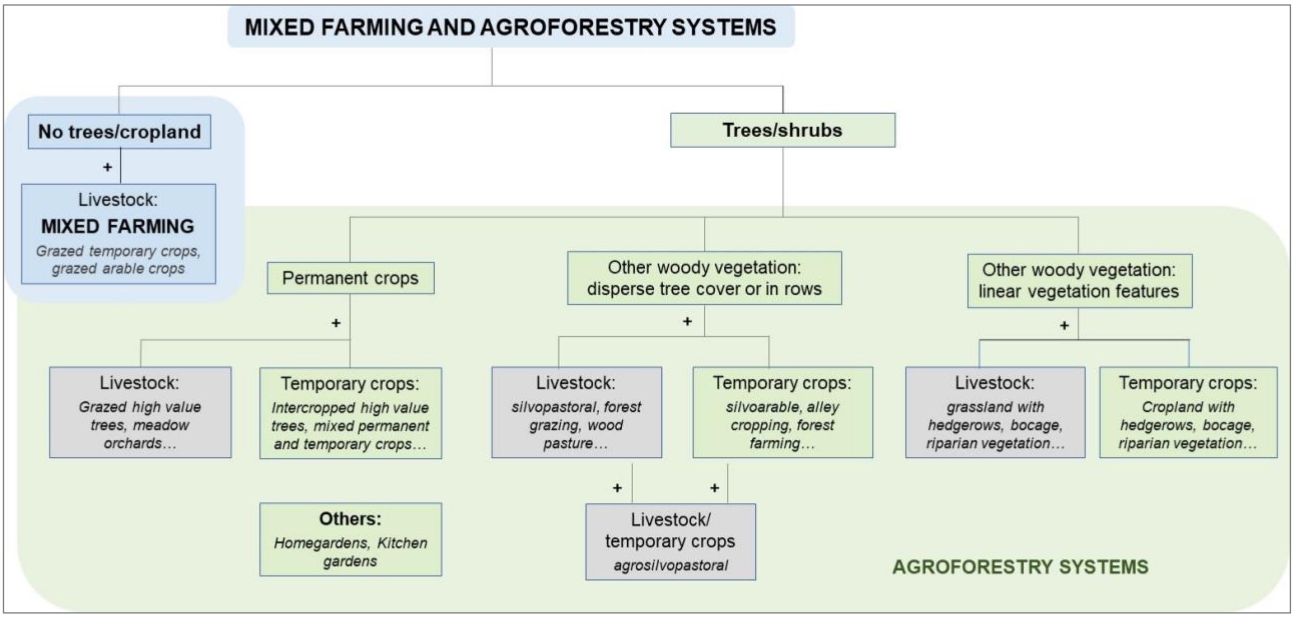

Figure 6. Principal categories of mixed farming and agroforestry systems in Europe using LUCAS data (examples in italic letters).

Once all points have been selected and classified, the number of points corresponding to each MF/AF class and for each country was obtained and integrated into a Geographical Information System (GIS). In order to estimate the surface extent of a MF/AF system for a European member state, the number of points obtained in the analysis is divided by the total number of LUCAS points of this country and multiplied by its surface area:

*Surface area of MF/AF system of a member state (km^2) = (N points MF/AF) / (total points) * country surface area (km^2).*

It is important to note that the result does not represent the real surface area but an estimate based on the proportion of MF/AF with respect to the total number of sample points in a country. The sum of the areas represents an estimate of the total surface area of mixed farming and agroforestry systems in Europe, and, off course, only includes those MF/AF systems which are identifiable in LUCAS.

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5.3 Analysis of woody linear features

In order to study the role of linear features and its consideration as a MF/AF system, different woody linear features (WLF) were selected and combined with land covers and management (i.e. grazing) (Table 8). For this, the LUCAS transect data was used, available only for survey years 2012 and 2015. These transects describe all features found in a transect of 250 m starting at each survey point in an easterly direction (Figure 5), using the same LUCAS cover codes but also new codes dealing with linear elements of the landscape.

The general rule is that all features wider than 3 meters are land cover features coded with standard LC codes and all features wider than 1 meter but narrower than 3 meters are coded with linear feature codes. These should be continuous in their linearity, i.e. if there is a gap this should be less than 20 meters (e.g. gap in a hedge) but the linear feature as a whole should be continuous (LUCAS, 2012).
We selected those linear features which are formed by woody plants and, hence, included the following types as defined and described in Eurostat (2013):

a) **Heath/Shrub:** represent heath, shrub and tall herb fringes.
b) **Single bushes/trees:** represent real single trees being a "landmark" in a grassland/bushy or cropped area.
c) **Avenue trees or other line of trees:** represent one line of trees, not clustered trees; or two lines of trees (avenue trees) separated by a road.
d) **Conifer hedges**
e) **Bush/tree hedges/coppices visibly managed:** represent hedgerows visibly managed, e.g. pollarded (generally < 5 m height).
f) **Bush/tree hedges not managed:** represent hedgerows which are not managed, with single trees or shrubland deriving from abandonment. Shrub or wood margins are found as field boundaries within agricultural land or alongside roads or water courses.
g) **Grove/Woodland margins:** represent grove and woodland margins (if no hedgerow).

Once the points with WLF were selected, their types (codes from LUCAS), were annotated and classified using the criteria presented in Figure 8. The classes are: Permanent crops, Grazed grasslands and Arable crops with WLF. Those points that were already classified as MF/AF systems and with WLF were analysed separately, maintaining their original class. In the LUCAS survey 2012, from a total of 270,276 transects, the length of each woody linear element was determined in a sample of 1,283 transects (Eurostat, 2013). The information of the sample transects was used to calculate the average length (m) of each type of WLF of our classified points. To estimate surface areas occupied by the WLF the average length was multiplied by 2 m, which represents their average width as they are by definition 1 to 3 metres wide. Narrower or wider elements are not considered linear features.

Using the mean lengths of each WLF their proportion with respect to transect length is calculated in the following way:

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Proportion of WLF type in a transect (%) = total length of WLF type (m) / transect length (250 m) · 100

Table 8. Criteria used to identify areas with woody linear features (WLF). LC1 = primary land cover; LC2 = secondary land cover; Undetermined means that any combination is possible.

CLASS	LC1	LC1 Codes	LC2	LC2 Codes	Grazing
Permanent crops with WLF	Permanent crops	B71-B83; B84K; BX2	Arable crops; Permanent crops; Woodlands; Shrublands; Grasslands; Bare lands and lichens/moss; Not relevant	B55; B71-B84; C10-C30; D10-D20; E10-E20; F10-F40; 8	No
Grazed grasslands with WLF	Grasslands without sparse tree cover	E20; E30	Undetermined		Yes
Arable crops with WLF	Arable crops	B11-B54; BX1	Undetermined		No

6 Results of LUCAS data analysis

6.1 Extent and spatial distribution of MF/AF systems in Europe

The total number of points corresponding to those classified as MF/AF systems for the 4 survey years is presented in **Error! Reference source not found.**. It should be noted that the number of member states considered in the analysis increased between 2009 and 2015, as shown in **Error! Reference source not found.**. Furthermore, point numbers also changed between the surveys. Therefore, the proportion of MF/AF with respect to the total number of points is a more adequate figure for indicating change. Between 2009 and 2012 the proportion of MF/AF points increased from 3.0% to 5.1% and decreased afterwards, with a value of approximately 3.0% in 2018, a proportion very similar to the one of 2009. These changes are further analysed in Section 3.4.

Table 9. Number of LUCAS points classified as MF/AF systems for survey years 2009, 2012, 2015 and 2018 and percentage of the total point number (countries included are presented in table 3).

Year	Total	MF/AF	% MF/AF
2009	234,484	7,109	3.03
2012	270,152	13,745	5.09
2015	338,725	13,495	3.98
2018	337,854	10,046	2.98

In the following, results are presented on the spatial distribution of MF/AF systems for survey year 2018 in EU-28. The estimated total surface area occupied by mixed farming and agroforestry in Europe is 132,955 km^2, which represents 3.0% of the total surface area and 7.7% of utilized agricultural land[3]. These figures do not include other land uses with woody linear features which are analysed separately in Section 3.3.

Figure 7 illustrates the surface areas occupied by the different MF/AF classes. Agroforestry dominates over mixed farming, occupying 87.4% of MF/AF systems. The predominant system is Silvopastoral which represents 77.7% of the total area occupied by MF/AF, followed by Home gardens with 12.1% (Figure 7. Surface area occupied by different MF/AF systems in EU-28 and percentages with respect to the total MF/AF extension (LUCAS survey 2018).Figure 7). Grazed arable crops present only 5.5% of the total MF/AF area. Agroforestry systems with permanent crops, either grazed (3.0%) or intercropped (0.8%) are relatively scarce. Surprisingly low is the representation of silvoarable and agrosilvopastoral systems with 0.6% and 0.2%, respectively.

[3] The utilized agricultural area in the EU amounts to 1,733,386 km^2 (last data from 2016: https://ec.europa.eu/eurostat/web/microdata/farm-structure-survey).

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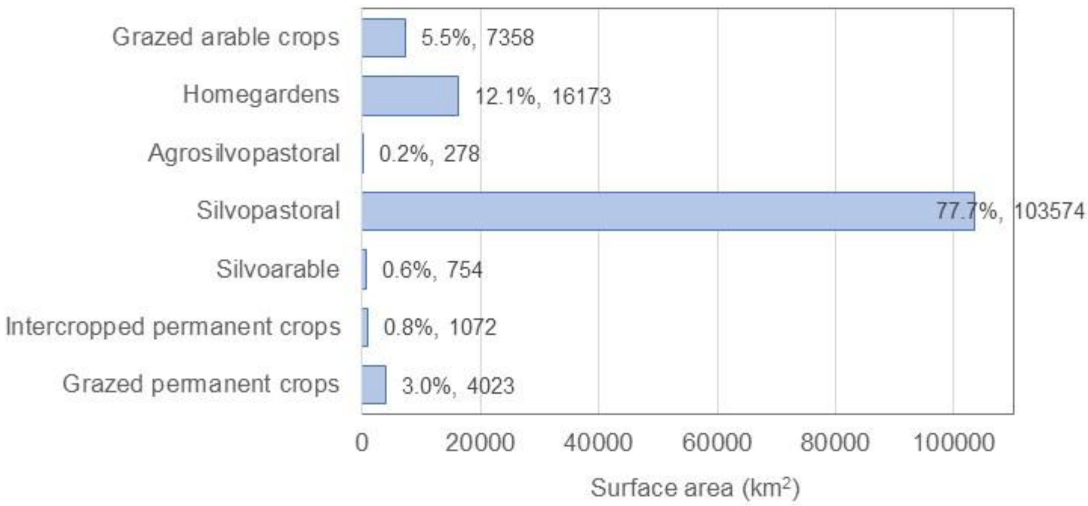

Figure 7. Surface area occupied by different MF/AF systems in EU-28 and percentages with respect to the total MF/AF extension (LUCAS survey 2018).

Regarding the extent of the different MF/AF classes by EU member states (Table 10), Spain is the country with the largest surface area (34,671 km^2), followed by Greece (16,934 km^2) and France (12,646 km^2). These three countries together amount to 54.4% of the total. Also, Italy and Portugal have an important share of MF/AF systems, with 7.4 and 5.3% of the total, respectively.

When expressing the surface area occupied by MF/AF systems as a percentage of utilized agricultural area (UAA) (Figure 8), Greece is the country with the highest value (37.2%). MF/AF systems occupy more than 20% of the UAA in Cyprus and Portugal, and >12% in Sweden, Spain and Slovenia. At the other extreme are countries like Poland, Germany, Denmark, The Netherlands, United Kingdom and Ireland with ≤ 2.5% of their UAA occupied by MF/AF systems.

The extent of different MF/AF classes for each EU country is presented in Table 10. The most remarkable data are summarized in the following:

- Silvopastoral systems combine land covers such as woodlands, shrublands and grasslands with sparse tree cover together with livestock breading. It is by far the most frequent class occupying 103,296 km^2, which represents 2.3% of EU-28 territory. Expressed as a percentage of the total surface area occupied by silvopastoral systems, Spain is the country with the largest share (30.4%), followed by Greece (14.3%), France (9.8%), Portugal (6.4%) and Italy (6.3%). These five countries together represent approximately 67% of the total. (Table *10*).
- Agrosilvopastoral is the combination of woody species and cropland on the same land, together with grazing livestock. Only 278 km^2 were classified as agrosilvopastoral, and was present only in Portugal, Spain and Italy.

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Table 10. Extent of different AF/MF systems classes (km²) by country (EU-28) for the survey year 2018. PC – permanent crops, ASP - agrosilvopastoral.

Country	Grazed PC	Inter-cropped PC	Silvoarable	Silvo-pastoral	ASP	Home-gardens	Grazed arable crops	Total MF/AF
Spain	346	145	324	31477	112	938	1329	34671
Greece	908	83	0	14743	0	355	845	16934
France	344	53	26	10091	0	1589	543	12646
Italy	203	160	21	6566	11	1719	1132	9811
Portugal	244	116	257	6665	129	528	463	8402
Romania	670	86	0	4576	0	2053	570	7954
Sweden	17	17	0	4774	0	201	84	5093
United Kingdom	14	0	0	3669	0	184	113	3980
Bulgaria	101	14	0	2414	0	535	506	3571
Germany	387	13	13	1188	0	1148	187	2938
Poland	54	41	0	392	0	1446	162	2094
Finland	0	105	21	1129	0	586	63	1903
Hungary	17	34	17	304	0	978	34	1383
Czechia	55	28	0	248	0	939	69	1339
Ireland	0	0	0	1195	0	14	28	1237
Austria	28	19	9	816	0	285	9	1167
Croatia	27	13	0	788	0	227	0	1055
Lithuania	57	0	0	85	0	598	214	954
Slovakia	0	0	0	169	0	761	17	948
Latvia	12	0	0	132	0	469	72	685
Slovenia	74	0	0	411	0	137	0	622
Belgium	34	0	0	293	0	142	17	486
Denmark	0	0	0	359	0	58	58	475
Netherlands	22	0	0	298	0	22	15	358
Estonia	0	0	0	170	0	119	0	289
Cyprus	16	32	0	152	0	28	60	288
Luxembourg	0	0	0	118	0	13	0	131
Malt	0	0	0	0	0	8	0	8

- Silvoarable is a land use system where woodlands, shrublands or grasslands with disperse tree cover are combined with arable (temporary) crops and only occupies 752 km² in the EU or 0.04% of UAA. It is only found in some European countries, corresponding 42.9% of its total to Spain and 34.1% to Portugal (34.1%). Smaller shares are present in France (3.5%), Italy (2.8%), Finland (2.8%), Hungary (2.2%), Germany (1.8%) and Austria (1.3%).
- Grazed permanent crops combine permanent crops and grazing livestock. Its extension is 4,023 km² and are found in almost all EU-28 countries, except in Denmark, Estonia, Finland, Ireland, Luxembourg, Malt and Slovakia. This class is concentrated in the following countries: Greece (22.6%), Romania (16.7%), Germany (9.6%), Spain (8.6%), France (8.6%), Portugal (6.1%) and Italy (5.0%), representing, as a whole 77.1% of the total area of grazed permanent crops.
- Intercropped permanent crops combine permanent crops as LC 1 and temporary crops as LC2, with a total extension of only 1,072 km² in the EU. The highest concentration of this land use system is encountered

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in Italy (14.9%), followed by Spain (13.5%), Portugal (10.8%), Finland (9.8%), Romania (8.0%) and Greece (7.8%). Intercropped permanent crops class is not found in Belgium, Denmark, Estonia, Ireland, Lithuania, Luxembourg, Latvia, Malt, Netherlands, Slovenia, Slovakia and United Kingdom.

- Grazed arable crops are a combination of temporary crops and grazing livestock. This class occupies 7,358 km^2 in EU-28, equivalent to 0.43% of UAA. Grazed arable crops are found in almost all countries, except Croatia, Estonia, Luxembourg, Malt and Slovenia. Spain is the country with a higher concentration of this land use class (18.1%), followed by Italy (15.4%) and Greece (11.4%). Figure 9 depicts the point distribution of this land use class.
- Homegardens occupy 16,173 km^2, corresponding to 0.94% of UAA in the EU. They are found in almost all countries, with the highest percentage of its total surface in Romania (12.7%), followed by Italy (10.6%), France (9.8%), Poland (8.9%), Germany (7.1%), Hungary (6.1%), Czechia (5.8%) and Spain (5.8%).

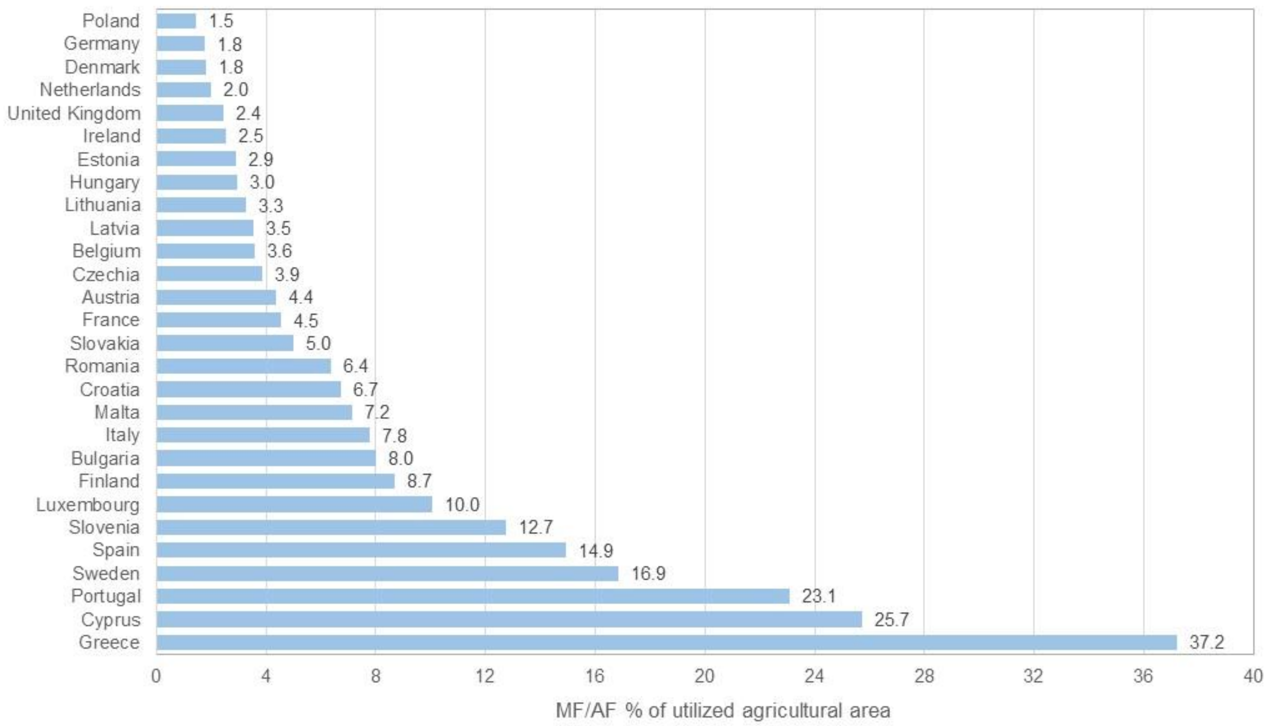

Figure 8. MF/AF extent as a percentage of utilized agricultural area for EU-28.

6.2 MF/AF systems in different bioregions

6.2.1 Biogreographical regions in the EU

The European Union is divided into nine biogeographical regions (European Environment Agency, 2016) (Figure 9). The Continental bioregion[4] has the largest extent, occupying 29.4% of EU-28 territory, followed by Mediterranean (20.7%), Boreal (19.2%) and Atlantic (17.9%) bioregions (Table 11). Black Sea, Macaronesia and Steppic bioregions occupy less than 1% of the EU.

By countries, 89.5% of the Continental bioregion is distributed between Poland (23.4%), Germany (22.0%), France (14.3%), Romania (10.3%), Italy (6.9%) and Bulgaria (5.9%). The Mediterranean region is mainly composed of Spain (48.0%), Italy (17.9%), Greece (14.6%), Portugal (9.3%) and France (7.3%). Boreal areas are only found in Sweden (41.1%), Finland (38.1%) and the Baltic countries, Lithuania (7.7%), Latvia (7.7%) and Estonia (5.4%). The Atlantic bioregion is representative of the western half of France (34.4%), the United Kingdom (31.4%), northwest of Germany (9.0%), Ireland (8.9%), the northern coastal area of Spain (7.1%), the Netherlands, the western half of Belgium and of Denmark. The Alpine bioregion is characteristic of mountainous areas with two separated areas: one in the north of Sweden (22.8%) and northern Finland (4.3%) and the second in the Alps in Austria (13.9%), north of Italy (13.4%), France (8.2%) and Slovakia (9.2%) and the Carpathian Mountains of Romania (13.0%), and mountainous regions of Bulgaria (4.6%). The Pannonian bioregion occupies Hungary, south of Slovakia and northwest Romania. Steppic is located in the southeast of Romania, and the Black Sea bioregion is found in the south-eastern coastal area of Bulgaria and Romania. Finally, Macaronesia is represented by the Canary Islands in Spain and Madeira and Azores Islands in Portugal. The Arctic biogeographical region is not found in the European Union

Table 11. Surface area of biogeographical regions and their proportion of EU-28 territory. N – number of AF/MF points

Bioregion	Surface (km²)	% of the EU-28 territory	N
Continental	1286632	29.41	2804
Mediterranean	903606	20.66	2351
Boreal	839929	19.20	1691
Atlantic	780859	17.85	2005
Alpine	378451	8.65	850
Pannonian	126138	2.88	240
Steppic	37112	0.85	67
Black Sea	11332	0.26	32
Macaronesia	10062	0.23	0
TOTAL	4374122	100.00	10046

[4] The term bioregion is used as a short version of biogeographical region

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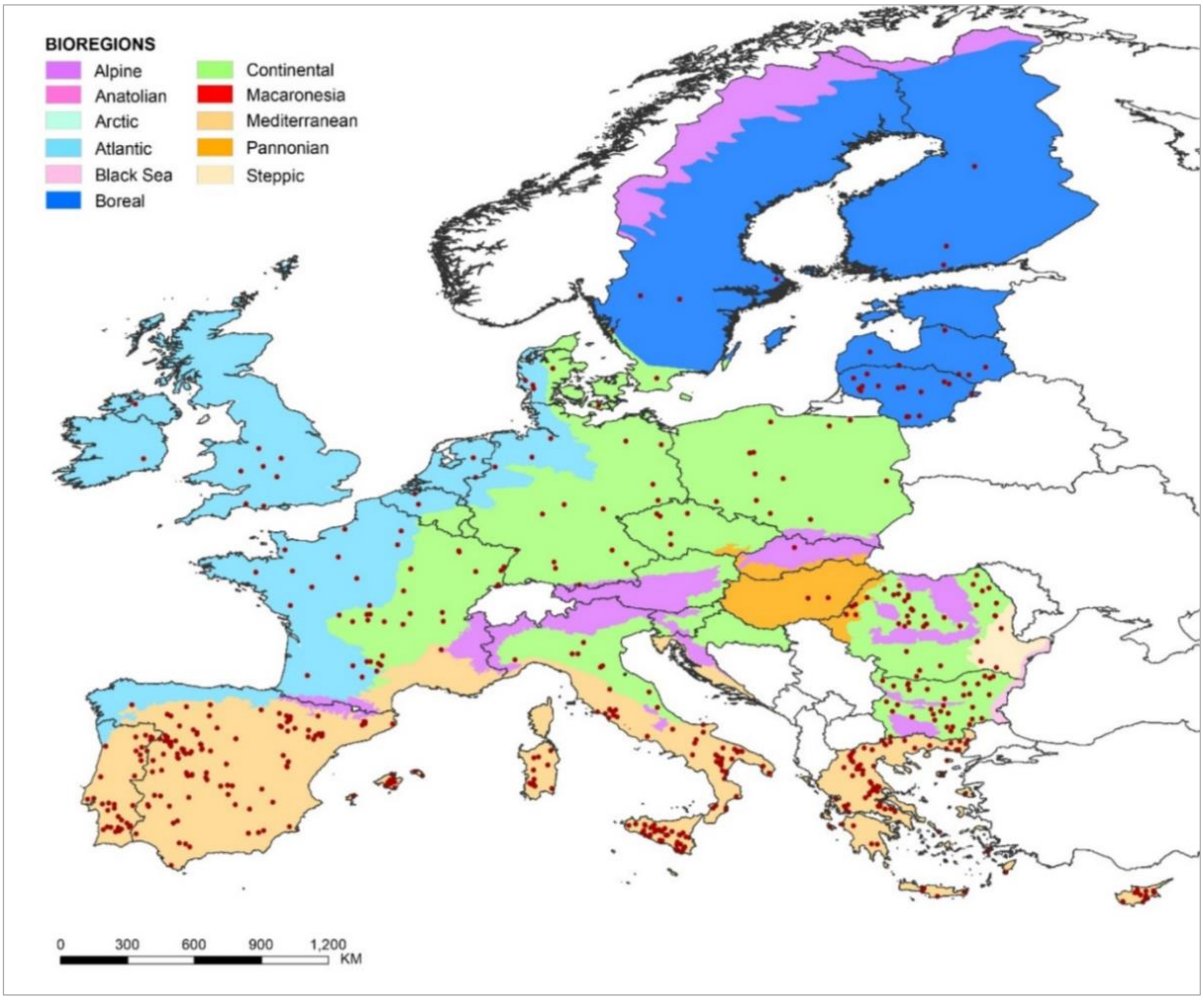

Figure 9. Biogeographical regions in EU-28. Shown are also points classified as grazed arable crops (2018). Country limits are also included.

6.2.2 Characterization of MF/AF systems classes by biogeographical regions.

In order to illustrate the spatial distribution of the different MF/AF systems in Europe several maps were produced presenting the corresponding points of a MF/AF class together with the biogeographical regions and the country limits. The most relevant maps are included here and the remainder are found in Annex 4 to 6. Table 12 presents the MF/AF point distribution by biogeographical region and EU member states. Furthermore, Table 13 shows the percentage share of the different MF/AF systems according to bioregion. The Macaronesia biogeographical regions did not register any point classified as MF/AF and is, hence, ignored in later analysis.

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Table 12. Distribution of MF/AF points according to countries and biogeographical regions. ALP – Alpine, ATL – Atlantic, BLS – Black Sea, BOR – Boreal, CON – Continental, MED – Mediterranean, PAN – Pannonian, STE – Steppic.

Country	ALP	ATL	BLS	BOR	CON	MED	PAN	STE	Total (%)
Austria	188				110				**2.97**
Belgium		65			45				**1.10**
Bulgaria	37		23		143				**2.02**
Croatia	20				70	34			**1.24**
Cryprus						89			**0.89**
Czech Rep.					115		5		**1.20**
Denmark		28			73				**1.01**
Estonia				91					**0.91**
Finland	17			554					**5.69**
France	73	645			537	114			**13.64**
Germany	2	153			479				**6.31**
Greece						384			**3.82**
Hungary							157		**1.56**
Ireland		185							**1.84**
Italy	155				219	435			**8.06**
Latvia				194					**1.93**
Lithuania				153	4				**1.56**
Luxembourg					7				**0.07**
Malta						1			**0.01**
Netherlands		176							**1.75**
Poland	21				546				**5.65**
Portugal		10				210			**2.19**
Romania	96		9		335		64	67	**5.69**
Slovakia	63						14		**0.77**
Slovenia	20				32				**0.52**
Spain	19	146				1084			**12.44**
Sweden	139			699	89				**9.23**
United Kingdom		597							**5.95**
Total	**850**	**2005**	**32**	**1691**	**2804**	**2351**	**240**	**67**	**10040**

Table 13. Distribution (%) of points classified as MF/AF classes by biogeographical regions for the survey year 2018 (each column sums 100%). N = point number of each bioregion. PC = permanent crops, ASP = agrosilvopastoral, AC = arable crops.

Bioregions	N	Grazed PC	Intercropped PC	Silvoarable	Silvopastoral	ASP	Grazed AC	Home-gardens
Alpine	850	4.16	1.23	0.00	4.27	0.00	0.36	6.06
Atlantic	2005	8.55	7.41	3.51	13.50	0.00	6.65	12.77
Black Sea	32	0.00	0.00	0.00	0.14	0.00	0.00	0.33
Boreal	1691	1.97	7.41	0.00	4.15	0.00	5.04	10.39
Continental	2804	33.55	18.52	7.02	12.35	0.00	23.20	40.34
Macaronesia	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mediterranean	2351	50.66	60.49	85.96	64.71	100.00	62.95	20.54
Pannonian	240	0.66	4.94	1.75	0.29	0.00	1.26	7.12
Steppic	67	0.00	0.00	0.00	0.58	0.00	0.54	2.54

In the following the main characteristics of MF/AF systems by biogeographical regions are summarized.

Silvopastoral systems are spread all over the European Union but the 7,805 points are unevenly distributed (Figure 10). The largest concentration is found in the *Mediterranean* area (64.7%), followed by the *Atlantic* (13.5%) and *Continental* bioregion (12.4%). A large number of points are located in the southwestern part of the Iberian Peninsula, Northern Spain, Sardinia and Corsica, Greece, southern Italy, the southern part of Central France, alpine areas of Austria and eastern Europe and in southern Sweden.
The types of land covers found in silvopastoral systems were analysed by bioregion (Table 14):

- In the Mediterranean area, they mostly consist of broadleaved woodland (45.0%), mainly broadleaved evergreen trees and, in a smaller proportion, thermophilous deciduous trees. Other significant land covers are grasslands with sparse tree cover (17.2%) and shrublands with and without tree cover (13.0% and 17.1%, respectively).
- In the Atlantic area, grazed grasslands with sparse tree/shrub cover (31.8%), broadleaved woodlands (30.4%), as well as shrublands without tree cover (27.0%) predominate.
- In the case of the Continental bioregion, grasslands with sparse tree/shrub cover dominate (53.9%), followed by broadleaved woodlands (24.9%). In both cases, mesophytic deciduous forests are the most abundant.

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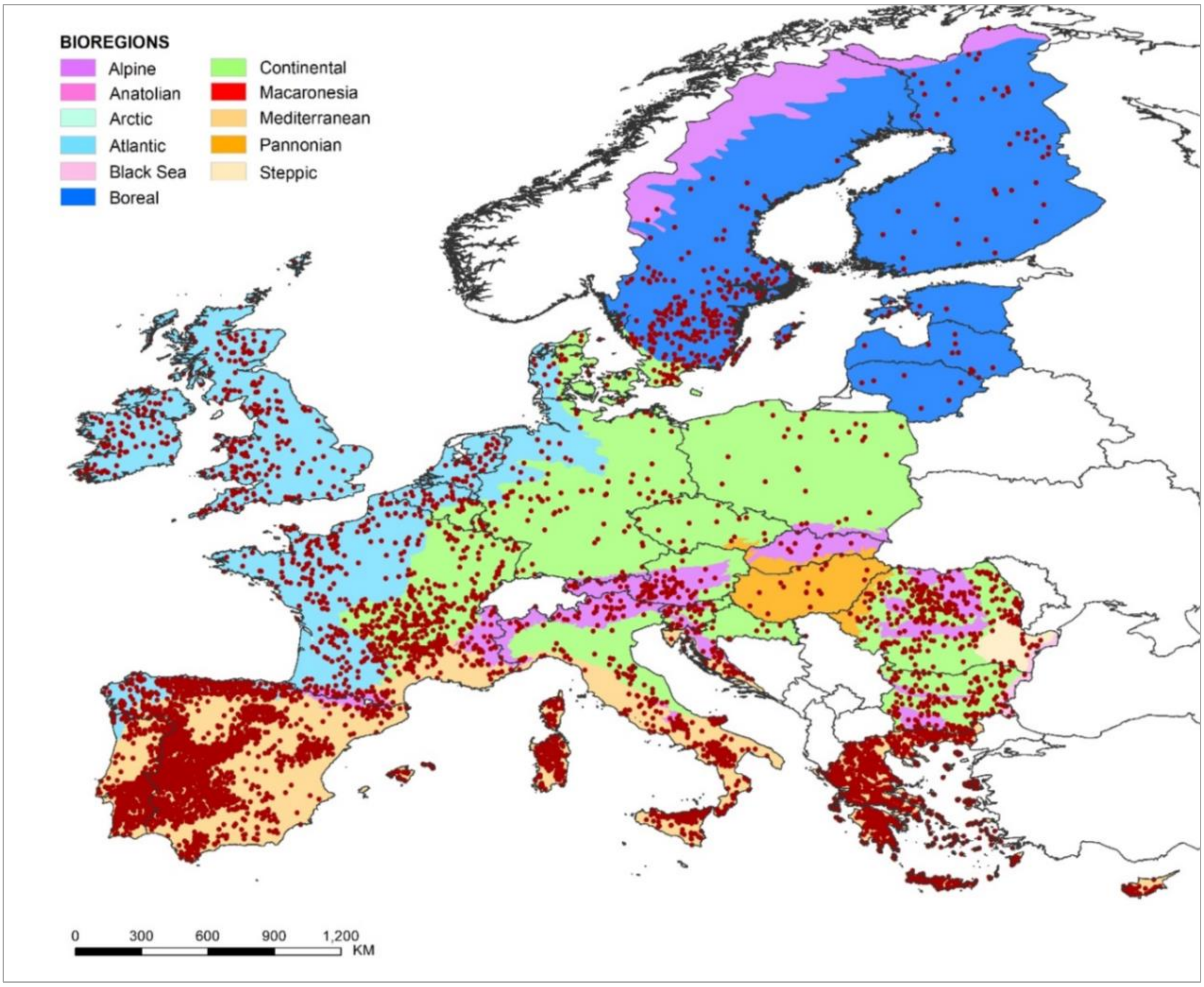

Figure 10. Distribution of silvopastoral systems by biogeographical regions in EU-28 (2018).

Agrosilvopastoral systems are only found in the Mediterranean, with just 21 points (Annex 3). They are almost exclusively composed of broadleaved evergreen trees in combination with cereals and leguminous species cultivated as livestock fodder and grazing livestock. As there are very few points, Agrosilvopastoral will be added to the Silvopastoral class when analysing temporal changes.

Silvoarable, with a total of 57 points, this MF/AF class is mainly found in the Mediterranean region (86.0%) (map included in Annex 5) and is composed primarily of broadleaved woodlands (93%). The most common temporary crops are: oats (29.8%), other leguminous and mixtures for fodder (14%), mixed cereals for fodder (10.5%), and to a lesser extent common wheat, barley and rye.

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Table 14. Proportion (%) of land covers in silvopastoral systems for different bioregions. ALP = Alpine, ATL = Atlantic, BSEA = Black sea, BOR = Boreal, CON = Continental, MED = Mediterranean, PAN = Pannonian and STE = Steppic.

Land cover	ALP	ATL	BSEA	BOR	CON	MED	PAN	STE	TOTAL
Broadleaved woodland	15.9	30.5	18.2	27.6	24.9	45.0	30.4	2.2	38.2
Spruce dominated coniferous woodland	12.0	0.6	0.0	3.7	0.4	0.6	0.0	0.0	1.2
Pine dominated coniferous woodland	3.6	2.6	0.0	8.4	1.9	3.9	0.0	0.0	3.6
Other coniferous woodland	3.6	0.3	0.0	0.6	0.4	0.9	0.0	0.0	0.8
Spruce dominated mixed woodland	2.4	0.2	0.0	6.2	1.1	0.1	0.0	0.0	0.6
Pine dominated mixed woodland	0.9	0.8	0.0	4.7	0.4	1.1	0.0	0.0	1.1
Other mixed woodland	2.4	0.7	0.0	4.3	1.0	1.1	0.0	0.0	1.2
Shrubland with sparse tree cover	6.3	5.8	0.0	4.3	5.9	13.0	13.0	2.2	10.4
Shrubland without tree cover	13.5	26.9	18.2	0.9	10.0	17.1	13.0	4.4	16.7
Grassland with sparse tree/shrub cover	39.3	31.8	63.6	39.1	53.9	17.2	43.5	91.1	26.1
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Grazed permanent crops point distribution is presented in Figure 11 (n=304). This agroforestry system is largely found in the Mediterranean (50.7%) and in the Continental bioregion (33.6%). Smaller numbers are distributed in the Atlantic domain (8.6%). The dominant permanent crops in the Mediterranean region are olive trees, while in the Continental and Atlantic areas the dominant fruit tree is apple. See Table 15 for more detailed information on permanent crop types.

Table 15. Proportion (% total number of points) of crop types in grazed permanent crops by biogeographical regions. (pi = photo interpretation).

Permanent crops	Alpine	Atlantic	Boreal	Continental	Mediterranean	Pannonian	Total
Apple fruit	2.30	4.28	1.97	13.82	0.00	0.00	22.37
Cherry fruit	0.33	1.32	0.00	3.62	0.00	0.00	5.26
Nuts trees	0.33	0.99	0.00	4.61	6.58	0.66	13.16
Olive groves	0.00	0.00	0.00	0.33	38.16	0.00	38.49
Oranges	0.00	0.00	0.00	0.00	0.66	0.00	0.66
Other fruit trees and berries	1.64	0.66	0.00	7.57	1.32	0.00	11.18
Pear fruit	0.00	0.66	0.00	2.30	0.33	0.00	3.29
Permanent crops (only pi)	0.00	0.33	0.00	0.99	0.99	0.00	2.30
Permanent industrial crops	0.00	0.00	0.00	0.00	1.64	0.00	1.64
Vineyards	0.00	0.33	0.00	0.33	0.99	0.00	1.64
TOTAL	4.61	8.55	1.97	33.55	50.66	0.66	100.00

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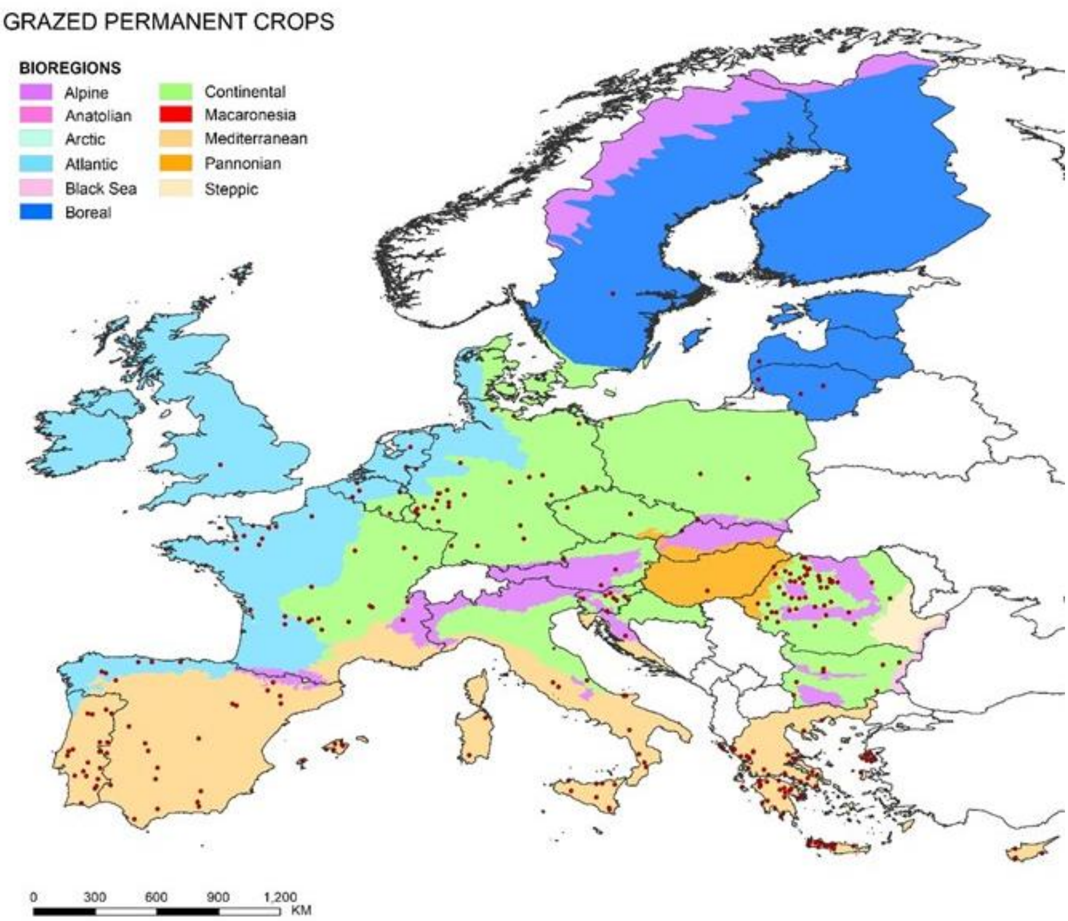

Figure 11. Distribution of grazed permanent crops in EU-28 (LUCAS data).

Intercropped permanent crops. The map showing the distribution of the 81 points corresponding to this agroforestry system is included in Annex 6. The majority of points are located in the Mediterranean region (60.4%), followed by Continental (18.5%). Similar to the grazed permanent crops, the dominant tree in the Mediterranean is olive, in association with cereals such as barley or oats, fodder crops or other fresh vegetables. Nuts and other fruit trees are also common there. In Continental Europe, quite a variety of fruit trees are present (apple, vineyards, pears, amongst others).

Grazed arable crops. This mixed farming system, which combines temporary crops and grazing livestock (556 points), is most frequent in the Mediterranean, with 63% of the total number of points (Figure 9). They are also abundant in Continental EU (23.2%) and lower numbers correspond to Atlantic and Boreal domains with 6.7% and 5.0% respectively. The most representative temporary crop depends on the bioregion. In the Mediterranean region, mixed cereals for fodder, oats and barley are the dominant crops, whereas in the Continental bioregion common wheat and lucerne are more frequent. Clovers and maize are typical of the Atlantic domain and other leguminous and mixtures for fodder correspond to the boreal region.

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Home gardens, with 1222 points is the second most frequent MF/AF system in the European Union (Figure 12). Large numbers of kitchen gardens are found in the Continental bioregion (40.3%), followed by the Mediterranean (20.5%). Other bioregions that have a fair amount of home gardens are Atlantic (12.8%), Boreal (10.4%), Pannonian (7.1%) and Alpine (6.1%). Table 16 summarizes the dominant permanent and temporary crops found in the different bioregions. The dominant fruit tree is apple, except in the Mediterranean where it is olive tree.

Table 16. Most frequent types of permanent and arable crops found in home gardens in the different bioregions (temporary crops were not identified).

Bioregion	Permanent crops	Arable crops
Continental	Apple trees	Other fresh vegetables, Temporary crops
Mediterranean	Olive groves	Other fresh vegetables
Atlantic	Apple trees	Other fresh vegetables
Boreal	Apple trees	Potatoes, Temporary crops
Pannonian	Apple trees, Nuts trees	Temporary crops, Maize, Tomatoes
Alpine	Apple trees	Other fresh vegetables

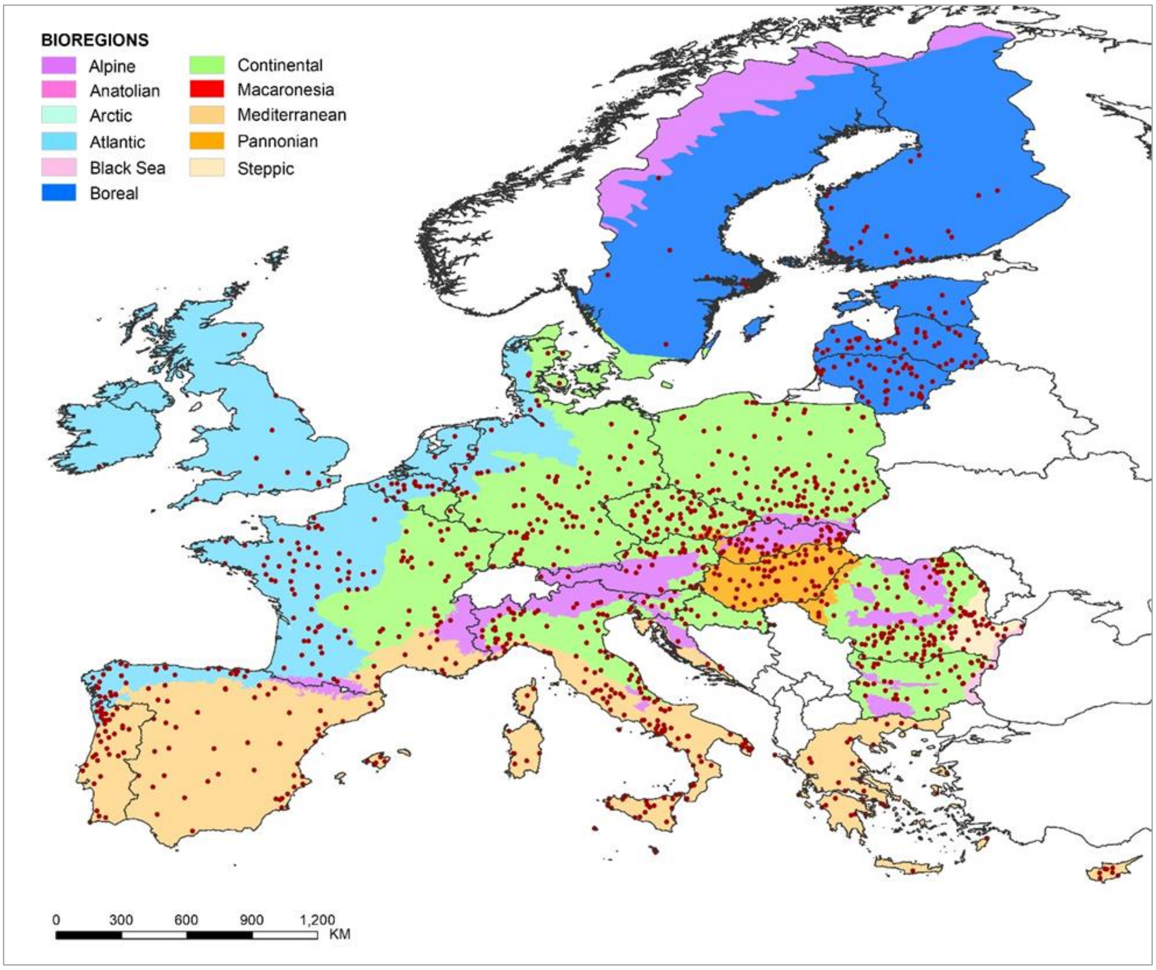

Figure 12. Distribution of home gardens by bioclimatic regions in EU-28 countries (2018).

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6.3 Woody linear features

6.3.1 Characteristics of woody linear features

Different woody linear features (WLF) were selected and combined with the land covers arable crops, permanent crops and grazed grasslands (Table 8). Data are only available for surveys 2012 and 2015 and were both analysed. In this report, however, only results from 2015 are presented. The types of WLF chosen in this study are: *heath/shrubs, single trees/shrubs, avenue trees, conifer hedges, hedgerows visibly managed, hedgerows not managed* and *grove/woodland margins*. Hedgerows not managed are those deriving from abandonment.

The total number of points with WLF in the survey of 2015 was 67,720, which represents 20% of the total number of LUCAS points and corresponds to an estimated extent of 893,945 km^2 (Table 17). It is important to note that these figures do not consider the number of WLF that were registered along the survey transect, i.e. considering whether they are present or not (1 or 0). Abandoned hedgerows are the most abundant type, representing approximately 30.2% of all WLF points, followed by heath and shrubs (18.8%), avenue trees (18.1%), visibly managed hedgerows (17.4%) and single trees and shrubs (14.7%). Less frequent are grove and woodland margins and conifer hedges (Table 17).

Table 17. Number of points with woody linear features in EU-28, percentage respect to total WLF point number, percentage respect total number of LUCAS points, estimated surface extension of WLF for survey year 2015.

Woody linear features	Points (n)	% WLF number	% of all LUCAS points	Surface (km^2)
Heath and shrubs	12,700	18.75	3.75	167,648
Single trees and shrubs	9,919	14.65	2.93	130,937
Avenue trees	12,243	18.08	3.61	161,615
Conifer hedges	822	1.21	0.24	10,851
Hedgerows visibly managed	11,820	17.45	3.49	156,031
Hedgerows no managed	20,421	30.15	6.03	269,569
Grove and woodland margins	3,148	4.65	0.93	41,555
Total	67,720	100.00	19.99	893,945

In the 2012 LUCAS survey a sample of transects were chosen and the length of different linear features determined (method described in EUROSTAT, 2013). The average length for each individual WLF type of this exploration is presented in Table 18. These values were used to estimate the proportion of WLF per transect, i.e. extrapolating the average length of a WLF type to the number of times it appears in a survey transect (remember that in the LUCAS surveys only the number of times a linear feature appears along a 250 m transect is annotated). With this extrapolation the average length of each WLF per transect is calculated, as well as its mean proportion (%) occupied in the transects.

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Table 18. Average length of each WLF element and sample size of the linear feature sampling of LUCAS 2012.

Woody linear features	Average length (m)	Samples
Heath and shrubs	2.1	90
Single trees and shrubs	4.7	25
Avenue trees	7.7	63
Conifer hedges	1.5	6
Hedgerows visibly managed	3.6	95
Hedgerows not managed	4.0	79
Grove and woodland margins	3.8	18
Total		376

Table 19 shows the results obtained from extrapolation of the mean linear feature widths (Table 18) to our selected points. Avenue trees as the ones with the highest average length in a transect (9.8 m), followed by managed and abandoned hedgerows with 5.5 and 5.2 m, respectively. Furthermore, results indicate slight changes between 2012 and 2015, with an increase of the proportion of avenue trees and abandoned hedgerows and a slight decrease of managed hedgerows and heath and shrubs (Table 19).

These values also constitute crude estimates of the average surface occupied by a WLF type, as they correspond to the percentage cover of a 250 m transect. For example, managed hedgerows were estimated to have a mean percentage cover of 2.1% in 2015 (Table 19).

Table 19. Average length occupied by woody linear features for the sample transects of survey year 2012 and estimated proportions (%) for transects of survey years 2012 and 2015.

Woody linear features	2012 (m)	% of transects 2012	% of transects 2015
Heath and shrubs	3.6	1.4	1.3
Single trees and shrubs	5.0	2.0	2.1
Avenue trees	9.6	3.8	4.1
Conifer hedges	1.8	0.7	0.7
Hedgerows visibly managed	5.5	2.2	2.1
Hedgerows no managed	5.2	2.1	2.3
Grove and woodland margins	4.1	1.6	1.9

6.3.2 Distribution of WLF in Europe

In the LUCAS 2015 survey, a total of 67,720 points presented WLF, of which 2,604 points were already classified as MF/AF systems (3.8%) and are, hence, not considered in the following analysis. The remaining points with WLF were classified regarding their principal land covers. Figure 13 depicts the proportions of the different types of WLF, showing that abandoned hedgerows dominate with 29%, followed by heath and shrubs (18%) and managed hedgerows and avenue trees, each 17%.

In the present study we considered several combinations of WLF with land cover classes as MF/AF systems. These are: arable (temporary) crops, permanent crops and grazed grasslands. Figure 14 presents the country share of these considered land uses with WLF. Almost a quarter of all considered land uses with WLF are

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found in France. The United Kingdom shares also a large proportion of the total number of points (12.6%), followed by Spain and Germany, with 9.2 and 9.1%, respectively. It has to be taken into account that this comparison does not relativize by country size, which results in larger countries having more points.

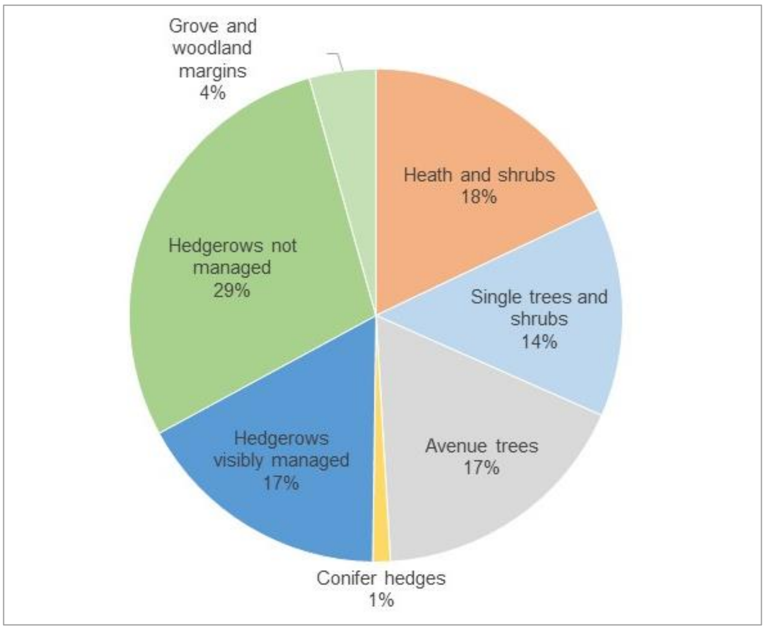

Figure 13. Wooded linear feature types as a percentage of their total number.

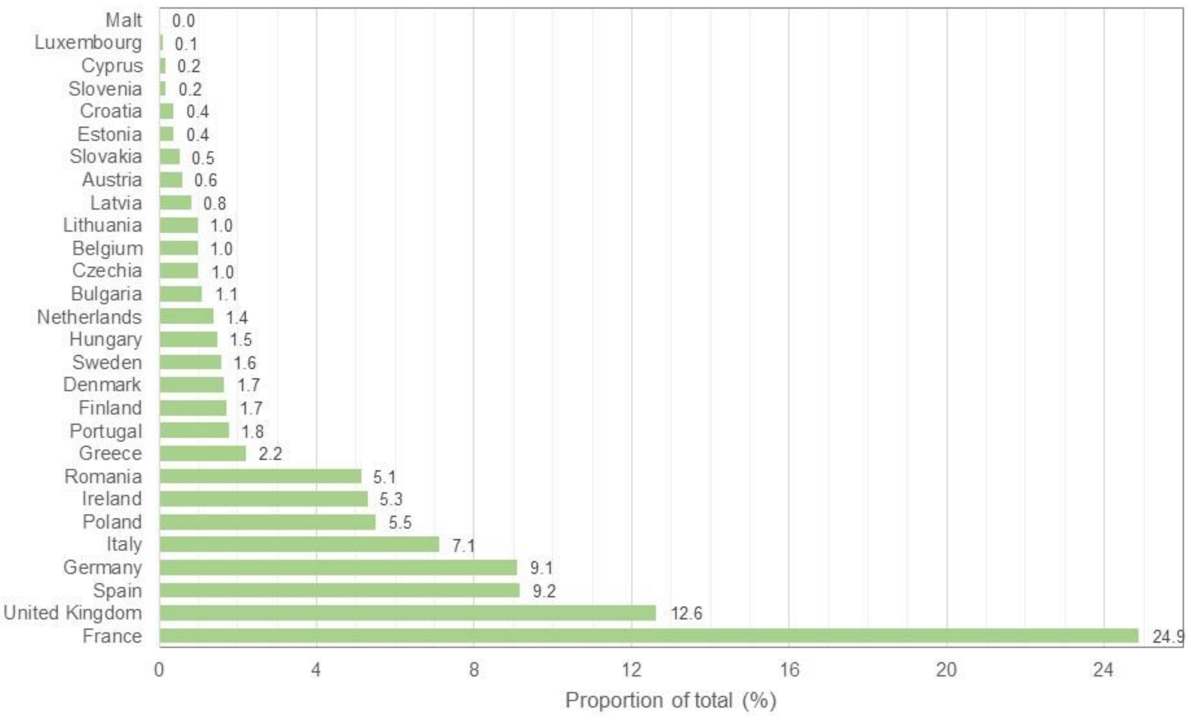

Figure 14. Country share (%) of classified areas with wooded linear features (croplands, permanent crops and grazed grasslands).

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Figure 15 shows the relative distribution of the three land use types with WLF, being arable crops the most relevant in EU-28 with 16,354 points and a share of 59%, followed by Grassland with grazing livestock (7,890 points, 28%).

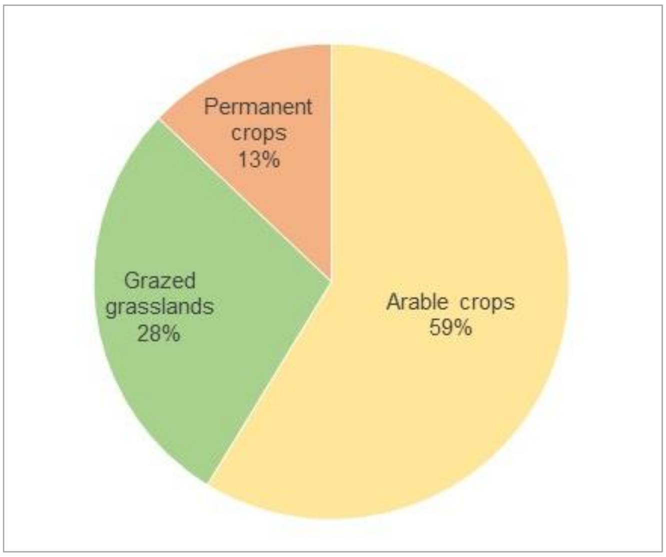

Figure 15. Land use classes of areas with woody linear features in 2015 (LUCAS data).

Regarding the spatial distribution of classified WLF points according to bioclimatic regions, 38.1% are located in Atlantic, followed by Continental (31.8%) and Mediterranean (22.1%) (Table 20). If differentiated by land cover type, WLF in arable crops dominate in the Atlantic and the Continental region, with 36.7% and 36.6%, respectively. Permanent crops with WLF are concentrated mainly in the Mediterranean, with almost 74%, and grazed grasslands are mainly found in the Atlantic region (55.6%), followed by Continental (29.2%) (Table 20).

Table 20. Proportion (%) of different types of land covers with woody linear features by biogeographic regions (2015).

Bioregions	Arable crops	Permanent crops	Grazed grasslands	Total
Atlantic	36.65	6.63	55.56	38.12
Continental	36.55	16.24	29.21	31.84
Mediterranean	16.80	73.91	9.46	22.11
Boreal	5.41	0.22	2.52	3.92
Pannonian	2.78	0.67	0.54	1.87
Alpine	0.61	1.42	2.41	1.22
Steppic	1.09	0.89	0.27	0.83
Black Sea	0.12	0.03	0.03	0.08
Total	100.00	100.00	100.00	100.00

Figure 16 shows the distribution of arable crops with woody linear features in Europe. By countries, they were mainly distributed in France (24.1%), Germany (12.3%), United Kingdom (11.2%), Poland (7.8%), Spain (7.2%) and Italy (7.2%). However, also other smaller countries presented numerous points with this land use

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system, such as in the boreal bioregion of southern Sweden, Lithuania and Latvia, as well as continental countries such as Bulgaria and Romania, and Greece and Portugal in the Mediterranean.

Grazed grasslands with WLF dominate in the Atlantic bioregion (55.6%), followed by Continental Europe (29.2%) and the Mediterranean (9.5%) (Figure 17). They are also quite abundant in parts of the Boreal domain (Latvia, Lithuania, Estonia and southern Sweden). Largest concentrations correspond to Ireland, United Kingdom and France.

Permanent crops with WLF are very much concentrated in the Mediterranean, with almost 74% of the total number of points corresponding to this land use system (Figure 18). They are also quite frequent in the Continental bioregion (16.2%), with larger concentrations in Romania, northern Italy and the eastern part of Poland. Permanent crops with WLF are nearly absent in Boreal and Alpine (except alpine Italy) and few are found in United Kingdom and Ireland.

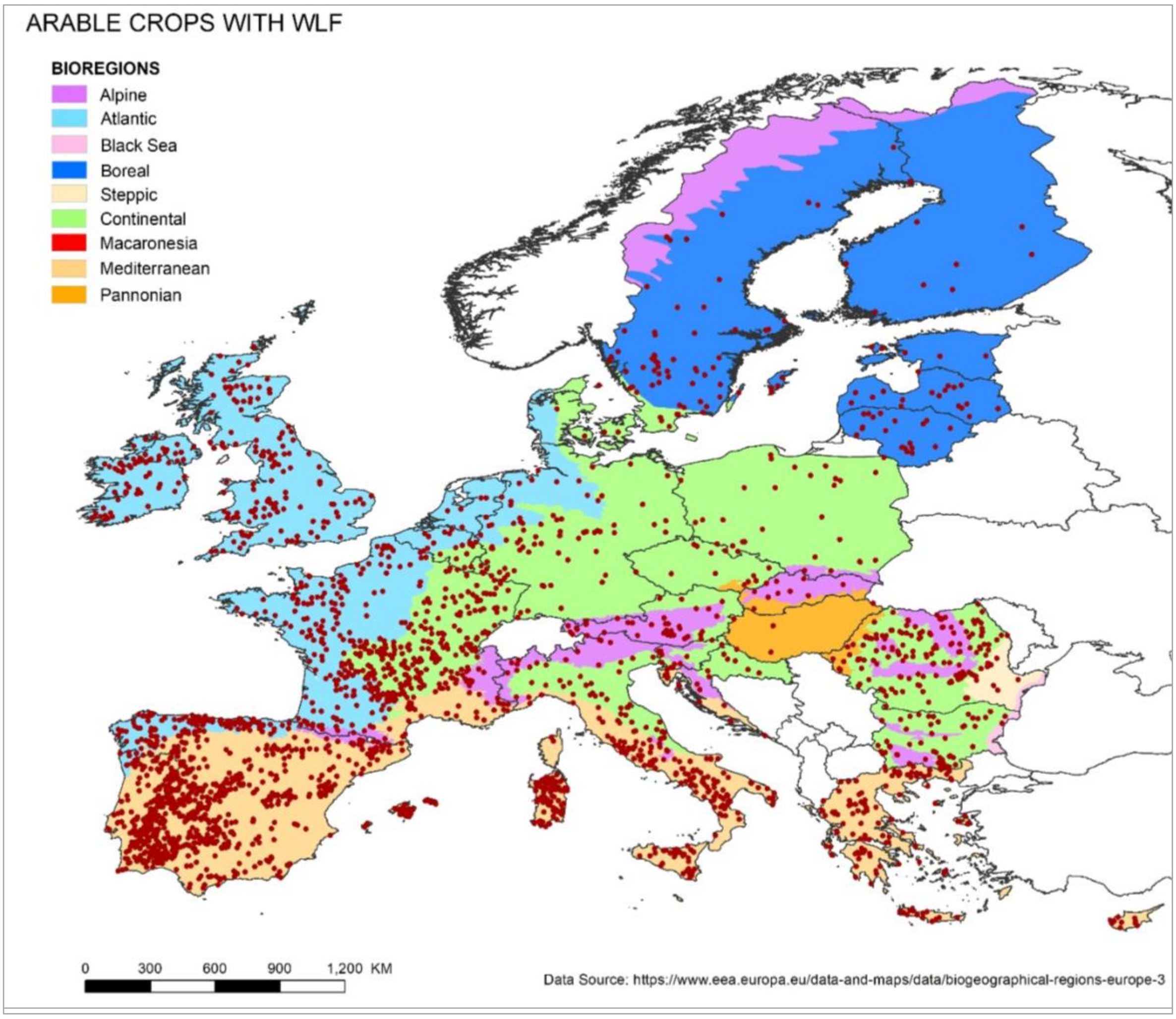

Figure 16. Arable crops with woody linear features in EU-28 countries and biogeographical regions (based on LUCAS survey 2015).

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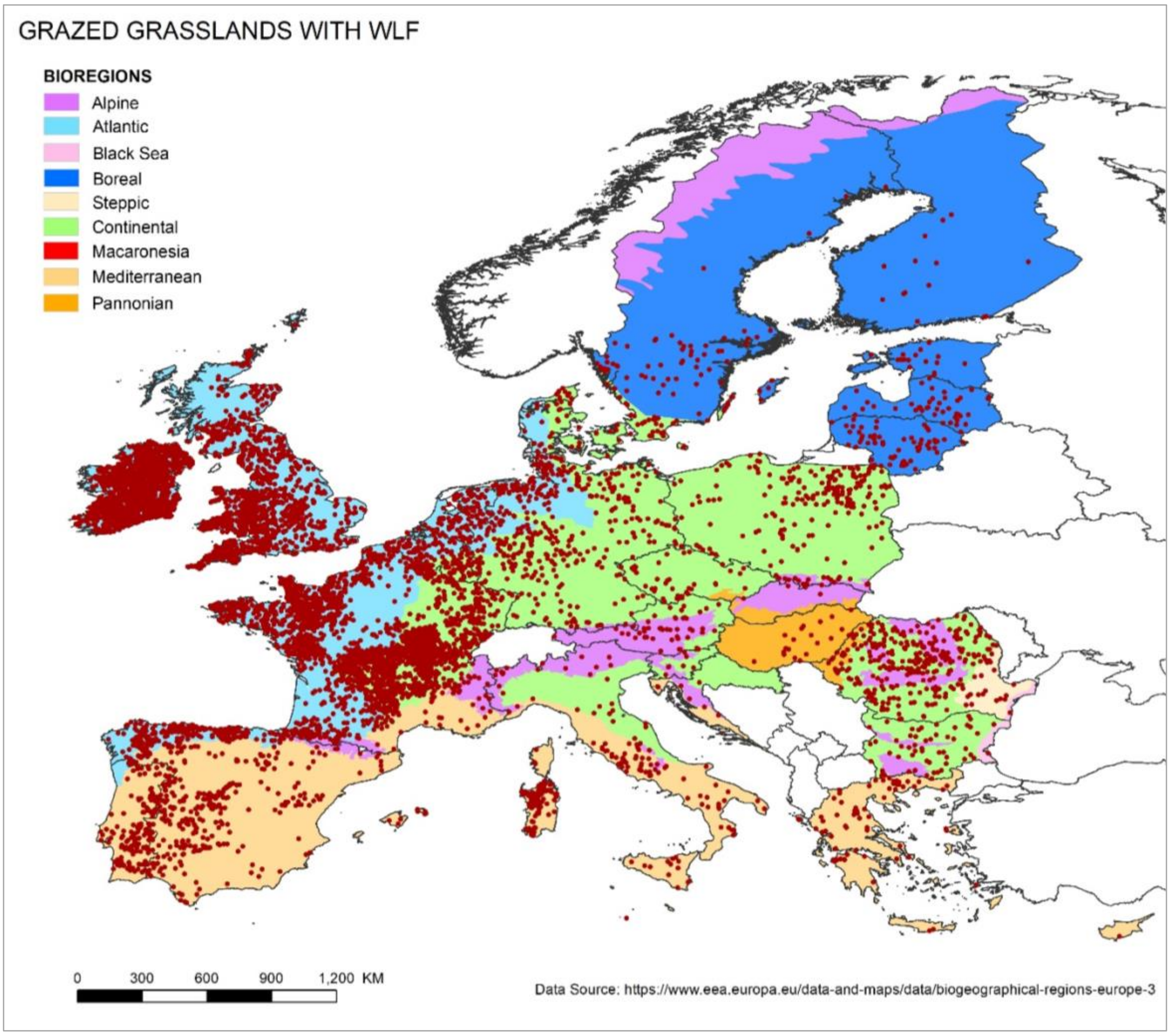

Figure 17. Grazed grasslands with woody linear features in EU-28 and biogeographical regions (based on LUCAS survey 2015).

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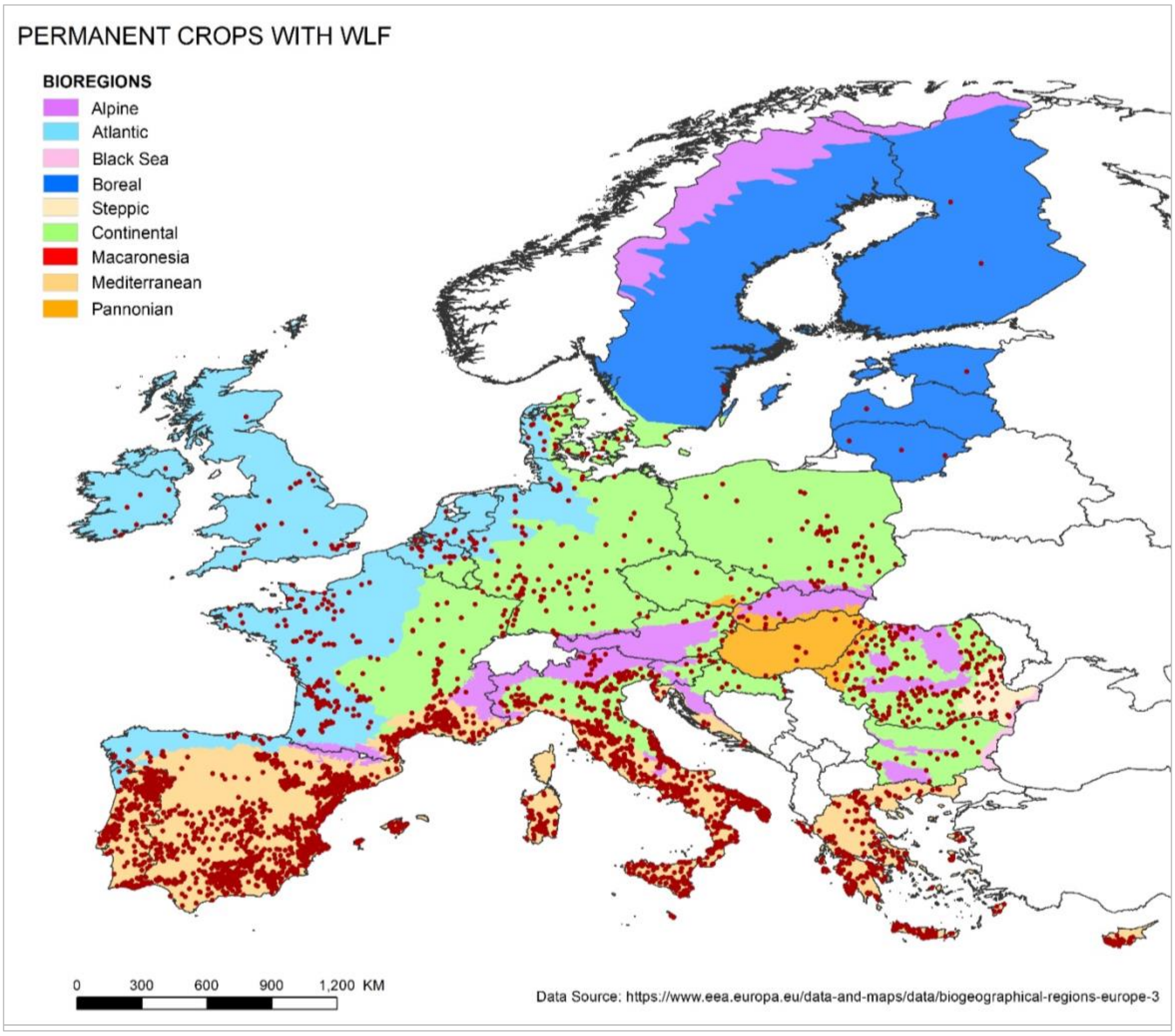

Figure 18. Permanent crops with woody linear features in EU-28 and biogeographical regions (based on LUCAS survey 2015).

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6.4 Changes of MF/AF systems

In this chapter the results of the analysis of temporal changes of MF/AF systems in Europe are presented. In order to be able to compare the data the analysis was limited to common countries, i.e. only those that formed the European Union in 2009 with 23 member states (not included are: Bulgaria, Cyprus, Croatia, Malta and Romania). Only data from LUCAS surveys of 2009 onwards were used because prior surveys had much fewer point numbers. Hence, a total of 4 surveys were available. The data is expressed as surface extent of MF/AF systems, which present the same proportions as the point numbers.

Table 21 shows the extent of each MF/AF system for the survey years, as well as the percentage differences registered between them. Included are also the changes taking place of the presence of grazing livestock. The total time elapsed was 9 years, from 2009 to 2018. Figure 19 illustrates these changes graphically.

The surface areas corresponding to Silvopastoral presented a strong increase (73.9%) between 2009 and 2012, corresponding to a difference of +70,118 km^2. In the following two periods a decrease took place (-18.2% and -29.1%). Very similar were the changes observed with grazing, which presented the same trend (Figure 19), with an increment between 2009 and 2012 of 68% and a following decrease between 2012 and 2018 of -48.6%. If only the changes between 2009 and 2018 are considered, Silvopastoral increased very slightly (0.9%), and Grazing decreased by -4.2% (Table 21).

It has to be taken into account that the agroforestry systems Silvopastoral, Grazed permanent crops and Silvoarable, as well as the mixed farming system Grazed arable crops, are not considered as MF/AF systems when no signs of grazing are observed in the LUCAS survey. Therefore, at least part of the changes observed must be related with variations of livestock grazing.

Table 21. Extent (km^2) and surface changes (%) of MF/AF systems classes and grazing for survey years 2009 to 2018. Data include only common countries (EU23). The percentage differences presented are with respect to the previous survey year.

AF/MF classes and grazing	2009	2012	2015	2018	Difference (%) 2009-12	2012-15	2015-18	2009-18
Grazed permanent crops	5518	8645	6169	3225	56.7	-28.6	-47.7	-41.5
Intercropped permanent crops	1280	1637	866	859	27.9	-47.1	-0.8	-32.9
Silvoarable	761	1146	748	753	50.6	-34.7	0.7	-1.0
Silvopastoral	94890	165008	134975	95718	73.9	-18.2	-29.1	0.9
Home gardens	11208	14245	12470	13417	27.1	-12.4	7.6	19.7
Grazed arable crops	9306	10626	7390	6160	14.2	-30.4	-16.6	-33.8
Grazing	109713	184279	148534	105117	67.96	-19.40	-29.23	-4.2

Interestingly, ungrazed land uses, such as Intercropped permanent crops, Silvoarable and Home gardens, also increased from 2009 to 2012. However, in the case of Intercropped permanent crops, its extent strongly reduced between 2009 and 2018 by -32.9%. The MF system Grazed arable crops did register a similar reduction in the 9-year period (-33.8%). The values of silvoarable systems remained stable and Home gardens

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is the only land use class which clearly increased between 2009 and 2018, with nearly 20% increase (Figure 19).

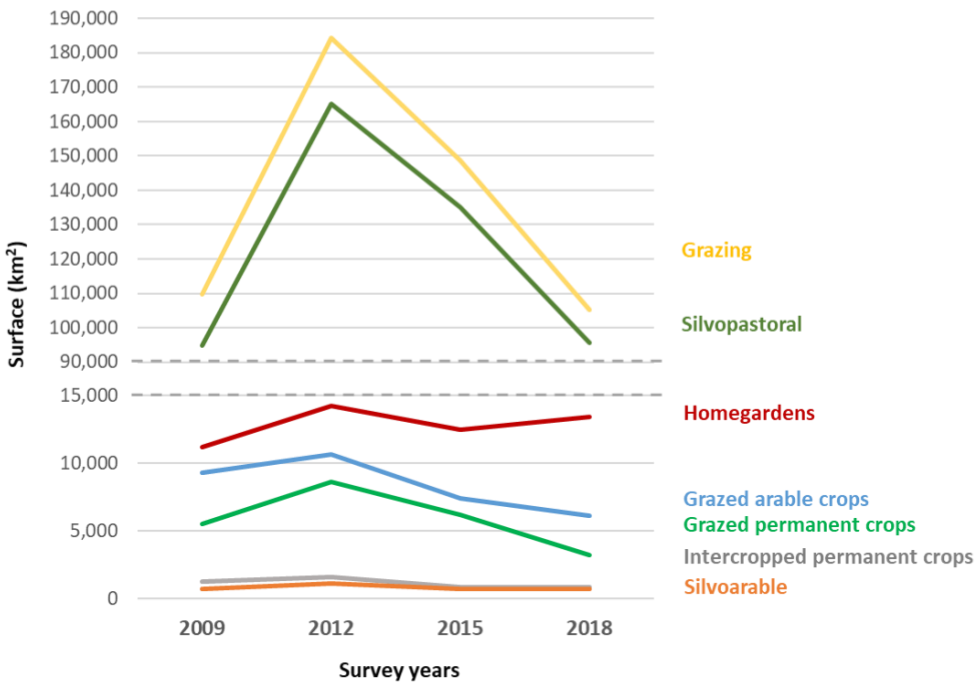

Figure 19. Extent (km^2) of AF/MF systems classes and grazing for survey years 2009 to 2018. Data include only common countries.

These results gave rise to a more thorough analysis by member states. Starting with Silvopastoral, the most extensive agroforestry system, Figure 20 depicts the changes which took place between 2009 and 2018. The surface area occupied by silvopastoral systems in Spain almost doubled between 2009 and 2012 with values of 32,766 km^2 and 62,231 km^2, respectively. The resulting difference of -29,465 km^2 makes up about half of the total increase of Silvopastoral between these two survey years (70,118 km^2, Table 21). As can be observed from Figure 20, in all other countries the extent of silvopastoral systems also increased between 2009 and 2012. In general, most countries did register a decrease afterwards (2012-2019).

If the period as a whole is considered, marked differences can be observed between EU23 nations, with Greece the only Mediterranean country where this agroforestry system increased notably between 2009 and 2018 (Table 22). There are also countries with a net increase, which does not show up in Figure 20 because the total extent of Silvopastoral is not very large there. This is the case of Estonia (+233%), Denmark (+136%), Luxembourg (+101%), Austria (+42%), Netherland (+30%) Sweden (+32%) and Finland (+21%). Non-Mediterranean countries with notable decreases are United Kingdom (-68%), Hungary (-67%), Lithuania (-58%), Slovakia (-44%), Germany (-38%) and France (-36%). These data indicate an increase of silvopastoral systems in many northern European countries, whereas in southern Europe a decrease is observed, except for Greece. It is also important to remember that new member states are not included in this analysis (Bulgaria, Cyprus, Croatia, Romania and Malt).

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Figure 20 illustrates the changes of MF/AF systems that took place between 2009 and 2018 by member states. In the Mediterranean, the proportion decreased, except for Greece and Malt. In United Kingdom, Ireland and France a decrease can be observed, whereas the northern countries (Finland, Sweden, Estonia, Latvia, Lithuania and Denmark) recorded increased surface areas. Central European member states, such as Germany, Poland, Czech Republic or Austria had little change in extent of MF/AF over the 2009-2018 period.

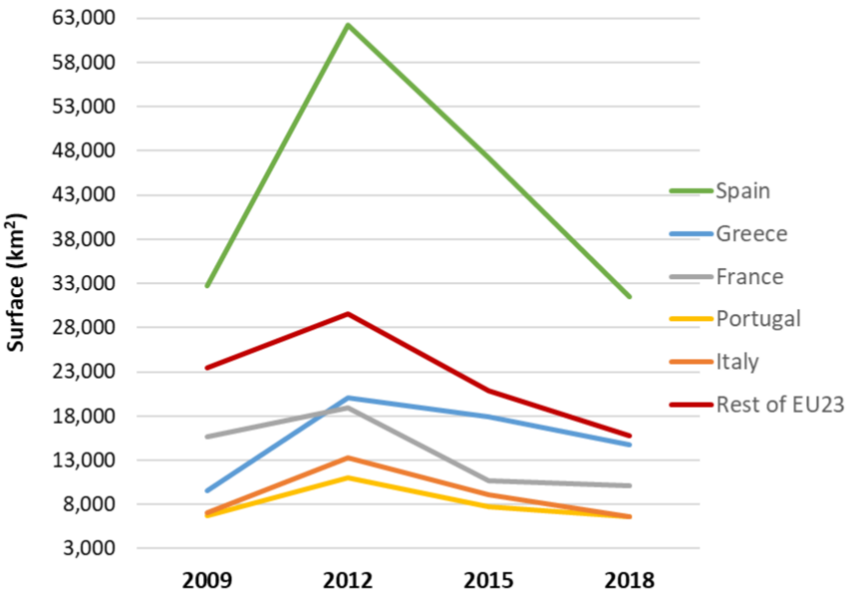

Figure 20. Surface extent of silvopastoral systems for survey years 2009, 2012, 2015 and 2018 in EU23.

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Table 22. Extent (km²) and surface changes (%) of silvopastoral systems for survey years 2009 to 2018. Data include only common countries (EU23). The percentage differences presented are with respect to the previous survey year.

Country	2009	2012	2015	2018	Difference (%)			
					2009-2012	2012-2015	2015-2018	2009-2018
Spain	32,766	62,231	47,236	31,477	89.93	-24.09	-33.36	-3.93
Greece	9,540	20,021	17,964	14,743	109.86	-10.27	-17.93	54.54
France	15,686	18,892	10,666	10,091	20.44	-43.54	-5.39	-35.67
Portugal	6,701	10,981	7,752	6,665	63.88	-29.41	-14.03	-0.53
Italy	7,030	13,243	9,149	6,566	88.39	-30.92	-28.23	-6.60
Sweden	3,609	4,810	6,280	4,774	33.27	30.56	-23.97	32.30
United Kingdom	11,476	12,585	5,076	3,669	9.67	-59.67	-27.72	-68.03
Ireland	1,512	2,710	1,411	1,195	79.28	-47.93	-15.31	-20.95
Germany	1,914	2,280	1,855	1,188	19.12	-18.62	-35.94	-37.90
Finland	936	1,582	903	1,129	69.11	-42.93	25.07	20.71
Austria	575	1,374	1,661	816	139.09	20.83	-50.86	41.95
Slovenia	371	525	495	411	41.68	-5.67	-16.98	10.96
Poland	472	873	652	392	84.77	-25.36	-39.86	-17.06
Denmark	152	175	117	359	14.79	-32.92	206.82	136.26
Hungary	928	381	540	304	-58.93	41.64	-43.75	-67.28
Netherlands	229	301	222	298	31.37	-26.05	34.16	30.33
Belgium	255	414	339	293	62.26	-18.18	-13.34	15.04
Czechia	254	372	469	248	46.55	26.24	-47.07	-2.08
Estonia	51	124	241	170	142.09	94.67	-29.32	233.08
Slovakia	305	419	231	169	37.72	-44.84	-26.87	-44.44
Latvia	101	234	156	132	130.77	-33.17	-15.42	30.44
Luxembourg	59	84	71	118	42.72	-15.14	66.10	101.18
Lithuania	203	302	174	85	48.88	-42.45	-50.86	-57.90

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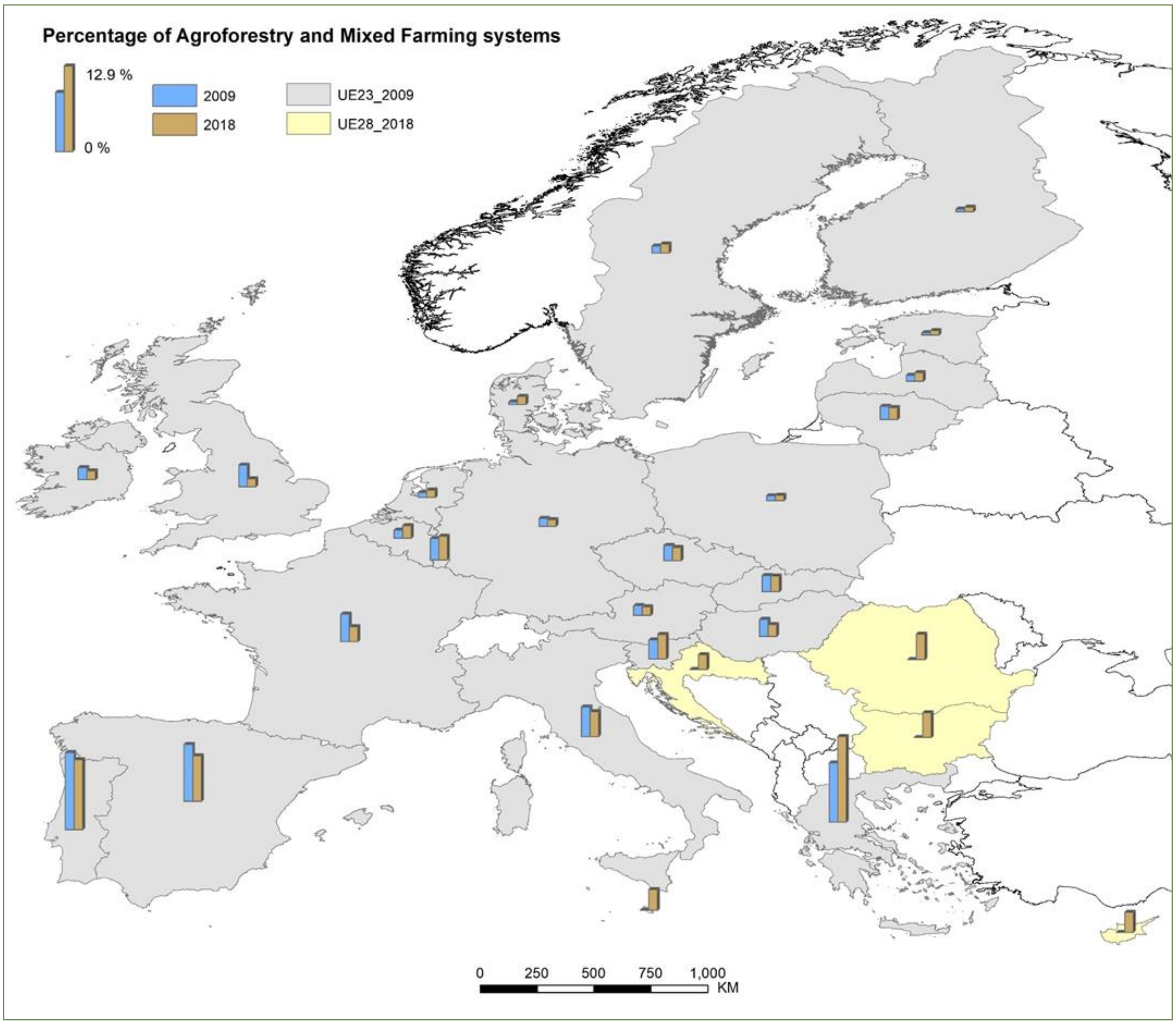

Figure 21. Changes of MF/AF systems 2009 and 2018. The values correspond to the extent expressed as a percentage of the territory of each EU member state.

A more detailed analysis of the changes that occurred between 2009 and 2018 was carried out using common points, i.e. those having the same geographical location between survey years. This analysis enables the determination of the type of change in a point and was carried out for silvopastoral systems. It implies using, not only the data classified as MF/AF systems, but the complete LUCAS dataset, as points may be gained or lost from a non-MF/AF land use. Table 23 presents the number of available points between survey years as well as the number of points that registered gains or losses and those that did not change.

Although this is the most appropriate way to analyse changes, the geographical location of the sample points in LUCAS surveys changed, so that the number of common points is lower than the number of classified MF/AF points. For example, in 2018 there were 7,805 points classified as silvopastoral systems, the number of common points between 2015 and 2018, however, were only 4,877 (Table 23). Furthermore, years 2009 and 2018 share only 3,057 points. It is obvious, that for MF/AF classes which are not very frequent in Europe,

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this type of analysis cannot be carried out. Therefore, in the following analysis only the most frequent class, silvopastoral, is analysed.

Table 23 presents the number of common points available for Silvopastoral between survey years 2009-2012, 2012-2015 and 2015-2018, i.e. three periods (P1, P2, P3) and the corresponding number of points that did not change or that were lost or gained. The difference between gains and losses constitutes the balance which was positive during P1 and negative in P2 and P3. It is also important to note that the number of common points in P3 was much lower than the previous two. What is not possible to do is to sum the balances of the periods because only 3,057 points coincide for the complete period between 2009 and 2018. However, these results confirm the same tendency than the one presented in the previous Section using the total number of class points, i.e. a strong increase of MF/AF from 2009-2012, followed by a decrease between 2012 and 2018.

Table 23. Balance of points for Silvopastoral between survey years.

	2009-2012, P1	2012-2015, P2	2015-2018, P3	2009-2018
Number common points	8,348	9,860	4,877	3,057
Gain	2,934	2,265	1,297	1,179
Loss	2,581	3,474	1,828	1,238
Not changed	2,833	4,121	1,752	640
Balance	353	-1,209	-531	-59

Table 24 presents the type of changes taking place in silvopastoral systems, but expressed as a percentage of the total number of coinciding points for the three periods. During P1, the largest percentage of gains were from not being grazed to grazed (18,5%) and from grazing not relevant to grazed (10.9%). Other types of gains were much lower. The most frequent losses were related with stopped being grazed (22.3%) and points that kept grazing but changed to another land cover (4.7%). The balance during this period was +4.2%. The changes produced during P2 and P3 were also mainly related with grazing, i.e. maintaining the land cover but gaining or losing the grazing activity. In the case of these two periods the balance was negative with a net loss of -12.3% in P2 and -10.9% in P3.

One important reflection related with these results is the strong increase of silvopastoral points between 2009 and 2012, followed by the decrease during subsequent years. Part of this increase is related with the change from "not relevant grazing" to grazing (10.9% or approximately 900 survey points). During the other periods this land management type was not important. The question that arises is whether there was a real land use change o, whether, in the survey year 2012, there was more abundant pasture so that grazing was more evident (see Section 2.1 about survey criteria). Rainfall in Mediterranean countries is highly variable and so is pasture production, so that the evidence of signs of grazing may vary too.

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Table 24. Observed changes of silvopastoral systems (%) in Europe23 between survey years. The last column presents the changes between 2009 and 2018 and has thus much fewer coinciding points.

Balance	Causes	2009-2012	2012-2015	2015-2018	2009-2018
No change		33.94	41.8	35.92	20.94
Gain	Change from other AF/MF class	0.43	0.62	0.29	0.43
	Change from other grazed land covers	3.22	2.63	2.15	3.37
	Change from not being grazed to being grazed	18.49	17.58	22.25	15.54
	Change from other non-grazed land covers	2.14	1.96	1.89	3.11
	Change from not relevant grazing to grazed	10.87	0.19	0.02	16.13
	Total gain	35.15	22.97	26.59	38.57
Loss	Change to other class	0.49	0.57	0.57	0.59
	Kept grazing but changed to other land cover	4.67	3.71	2.26	5.69
	Cessation of grazing	22.34	27.93	31.86	28.30
	Cessation of grazing and change of land cover	3.20	2.77	2.65	5.50
	Change to not relevant grazing	0.20	0.25	0.16	0.43
	Total loss	30.91	35.23	37.50	40.50
Gain-Loss		+4.24	-12.26	-10.91	-1.93

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7 Physio-geographic characteristics and the distribution of MF/AF

Mixed farming and agroforestry systems are found throughout Europe and in a wide range of geographic, climatic and physiographic environments. In the following two sections (4.1 and 4.2) it is analysed whether there are any topographic and climatic conditions under which MF/AF land uses preferably occur. Topography and climate are considered key natural factors in determining agricultural activity and therefore were chosen to characterize the spatial distribution of MF/AF in the European Union.

7.1 Topographic analysis

7.1.1 Methods

7.1.1.1 Datasets

Land use was derived from the LUCAS 2018 dataset, which provides European land cover and land use (see chapter 2). The LUCAS data was filtered to retain only those points representing MF/AF systems, divided into seven types: silvopastoral, silvoarable, agrosilvopastoral, grazed permanent crops, grazed permanent crops, intercropped permanent crops, and home gardens. Details of this procedure are described in chapter 2.

Topographic data were obtained from EUDEM v1.1 [link], a digital surface model, based on SRTM and ASTER GDEM data fused by a weighted averaging approach, with 25 m resolution. The digital surface model provides elevation data, from which several secondary indices are derived, i.e. slope, aspect, planform curvature, profile curvature, and wetness index. Wetness index is not yet included in this analysis, and still needs completing.

7.1.1.2 Topographic data sampling

The topographic indices were sampled at each of the LUCAS points classified as MF/AF, providing at-a-point values. Since LUCAS land use is likely to extend beyond the immediate location of the individual grid point, the topographic indices of the wider neighbourhood are considered here as well to complement the at-the-point value. Specifically, for each topographic index, the average value within a 250 m radius of the LUCAS point was calculated. The choice of a 250 m radius to define the neighbourhood is somewhat arbitrary. 50 m was deemed too small, being only one grid cell larger than the at-a-point resolution. 1000 m would be a maximum, as a larger radius would overlap with the neighbourhoods of any adjacent LUCAS points. Any value within the 75–1000 m range would be possible. A plot with this radius has a surface area of 196,350 m^2, i.e. almost 20 hectares.

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In addition, the standard deviation of topographic attribute values within the 250 m radius was calculated as well, to assess the mixed agriculture land use's tolerance of topographic variability. The only exception is aspect, for which average and standard deviation are meaningless values; instead, the majority aspect within the 250 m radius was reported. All calculations were done in ArcGIS v10.4.

7.1.1.3 Analysis

The overall distribution of topographic indices is analysed first (Section 3.3). Subsequently the analysis of topographic indices is repeated for each of the MF/AF land use types (Section 3.4), and for five geographic regions (Section 3.5; Table 25). Prior to these three topographic analyses a short overview of the LUCAS point data and of regional land use variations is given (Sections 4.1.2.1).

Table 25. Definitions of geographic regions.

Region	Boundary
Southern Europe	< 45 N
Northern Europe	> 55 N , > 2 E
Western Europe	> 45 N , < 55 N, > 2E , < 10 E
Eastern Europe	> 45 N , < 55 < , > 10E
UK and Ireland	> 50 N , < 2 E

7.1.2 Results

7.1.2.1 LUCAS point data and land use by region

In total 10,046 MF/AF land use points were identified in the LUCAS 2018 dataset. The dominant land use type is silvopastoral, whilst intercropped permanent crops, silvoarable, and agrosilvopastoral land uses occur only marginally (Table 26). See Section 3.1 and 3.2 for more detail on the distribution of MF/AF systems in Europe.

Table 26. MF/AF land use types in LUCAS dataset.

Land use type	Frequency (-)	Relative occurrence (%)
Silvopastoral	7805	77.7
Home gardens	1222	12.2
Grazed temporary crops	556	3.0
Grazed permanent crops	304	5.5
Intercropped permanent crops	81	0.8
Silvoarable	57	0.6
Agrosilvopastoral	21	0.2
Total	**10046**	**100.0**

MF/AF land uses are highly unevenly distributed across Europe, with 70% of all MF/AF land uses occurring in Southern Europe. When analysing the shares of each land use by region (Table 26), Silvopastoral land use is the dominant, comprising more than 70% of all MF/AF land uses in all regions except Eastern Europe. In Eastern Europe, silvolpastoral land use still is the most common (47%), but is closely followed by home

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gardens (40%), which are also popular in Northern Europe (22%) and Western Europe (19%). Intercropped permanent crops, silvoarable, and agrosilvopastoral land uses do not occur at all in UK and Ireland, and occur only marginally (<2% combined) in all other regions.

7.1.2.2 Topographic attributes – entire dataset

Elevation

Most MF/AF land use occurs at lower elevations, with 52% occurring below 400 m, 36% occurring between 400 m and 1000 m, and only 12% occurring above 1000 m (Figure 22). This broadly coincides with the distribution of elevations across Europe (Figure 22). However, MF/AF land use is underrepresented at the lowest elevations (<200 m), which comprise 40% of European terrestrial landmass but only 28.6% of MF/AF land use points. In contrast, MF/AF is slightly overrepresented at elevations between 200 m and 1200 m (Figure 22).

Because elevation, in general, tends to not change drastically within short distances, the distribution of average elevations within a 250 m radius is almost identical (not shown). Indeed, the standard deviation of elevations within a 250 m radius does not exceed 10 m for nearly half of the MF/AF land use points and exceeds 50 m for only 3% of the points (Figure 23).

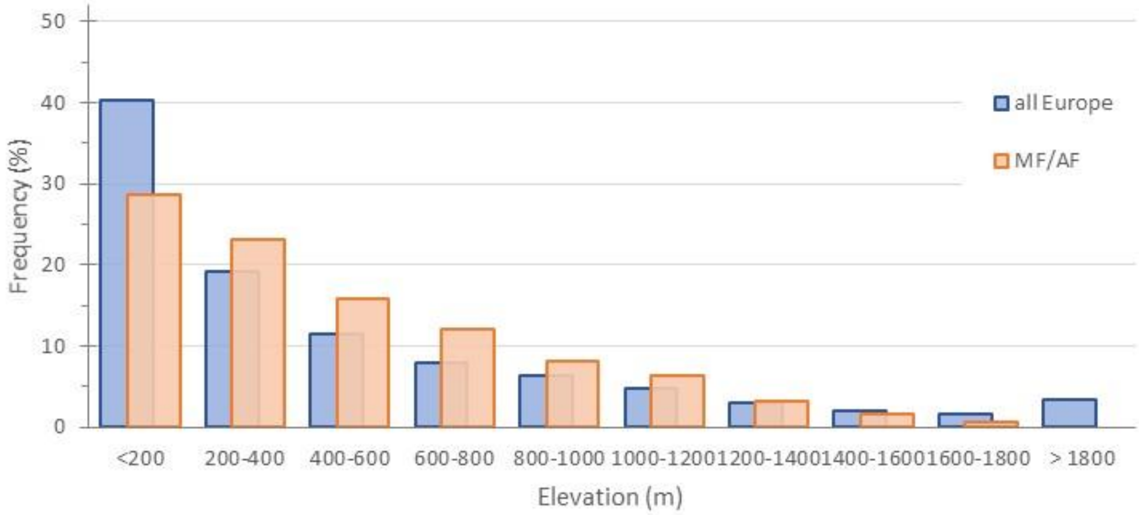

Figure 22. Distribution of elevations for all MF/AF land use points (orange) and all terrestrial datapoints in EUDEM (blue).

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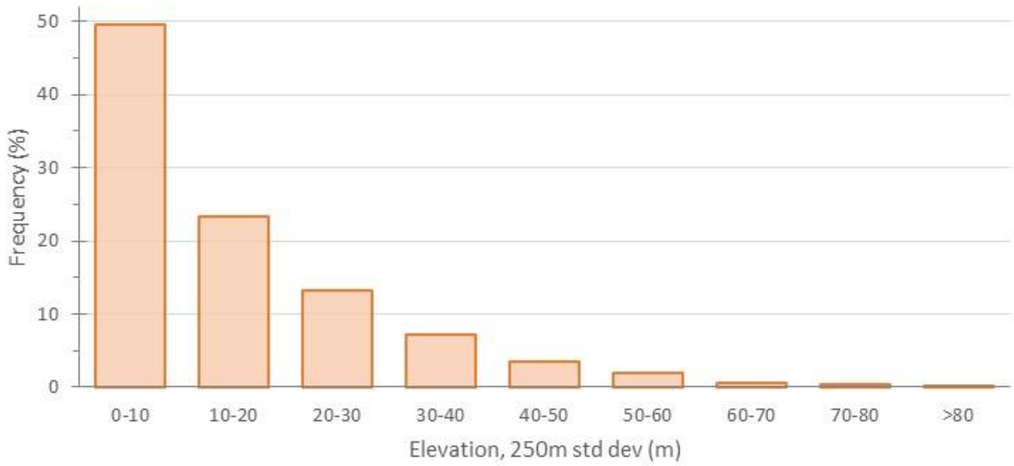

Figure 23. Standard deviation of elevations within 250m radius of MF/AF land use points.

Slope

MF/AF land uses mainly occur on gentle slopes, with 50% occurring on slopes lower than 5 degrees, 43% occurring on slopes between 5 and 20 degrees, and with only 7% occurrence on slopes greater than 20 degrees. This broadly follows the distribution of slopes across Europe (Figure 24), albeit that the lowest slopes are somewhat underrepresented while slopes between 5 and 20 degrees are overrepresented by MF/AF land use. This pattern persists when considering average slope within a 250 m radius of the LUCAS points (not shown). MF/AF land use preferably occurs in areas with steady slope, as the standard deviation of slopes within a 250 m radius mostly is less than 4 degrees (73% of all points) and only rarely exceeds 10 degrees (1.2% of all points) (Figure 25).

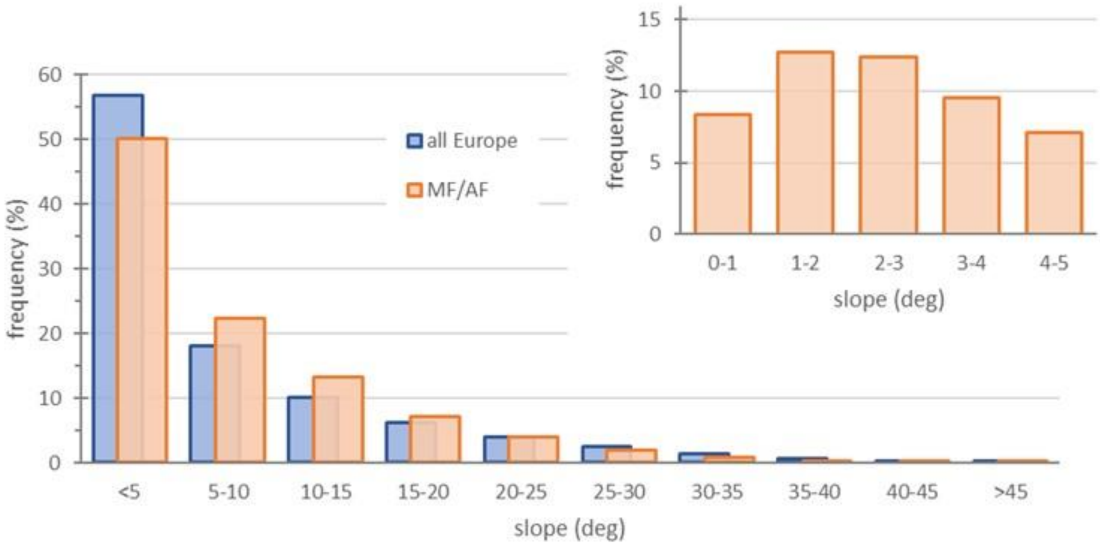

Figure 24. Distribution of at-a-point slopes for MF/AF land use points (orange) and all terrestrial datapoints in EUDEM (blue). Inset: distribution of at-a-point slopes for slopes less than 5 degrees (MF/AF land use points only).

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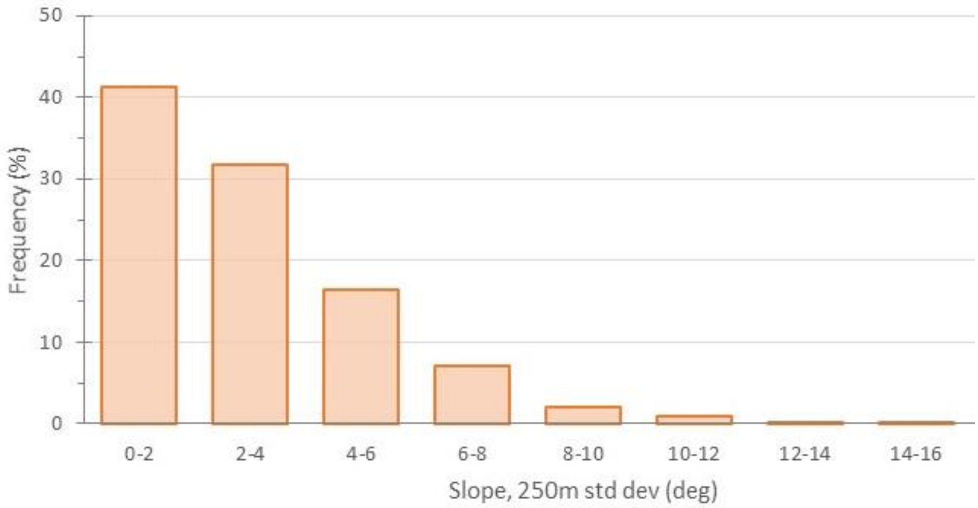

Figure 25. Standard deviation of slopes within 250 m radius of MF/AF land use points.

Aspect

At-a-point aspect of the MF/AF land use datapoints is quite evenly distributed, with a slight underrepresentation on north-facing slopes and a slight preference for south-west facing slopes (Figure 26A). The majority aspect within a 250 m radius also indicates a preference for south-west facing slopes (Figure 26B). Intriguingly, the majority aspect within a 250 m radius indicates a preference for slopes facing the intercardinal directions (NE, SE, SW, NW), whilst cardinal directions (N, E, S, W) are underrepresented, although this likely is a numerical artefact of the algorithm used.

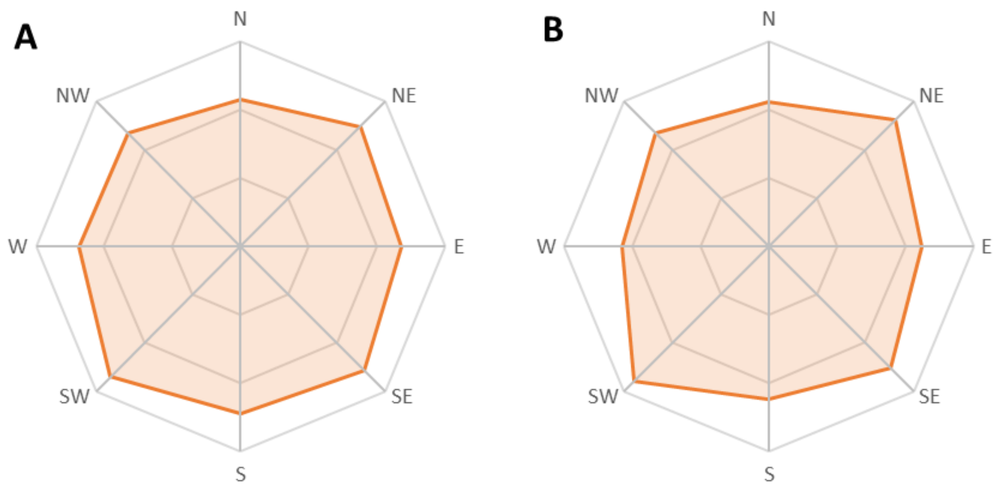

Figure 26. Distribution of slope aspect of MF/AF land use points. A) at-a-point aspects; B) majority aspect within 250 m radius.

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Planform curvature

Planform curvature is an indicator of water flow and sediment transport pathways on hillslopes. It is measured perpendicular to the direction of the maximum slope. Positive values denote convergence of flow pathways and negative values denote divergence of flow pathways, with greater absolute values indicating a stronger convergence or divergence of flow pathways. A planform curvature of zero represents a straight slope. Planform curvature of the MF/AF land use points is predominantly (89%) between -0.25 and +0.25 (Figure 27), indicating that most MF/AF occurs on relatively straight slopes with no flow convergence or divergence. The distribution of mean planform curvature within a 250 m radius is even more extreme, with 100% of datapoints having a value between -0.25 and +0.25 (not shown). Similarly, the standard deviations of planform curvatures within a 250 m radius are very low, and only exceed a value of 0.4 for less than 3% of all data points (Figure 28).

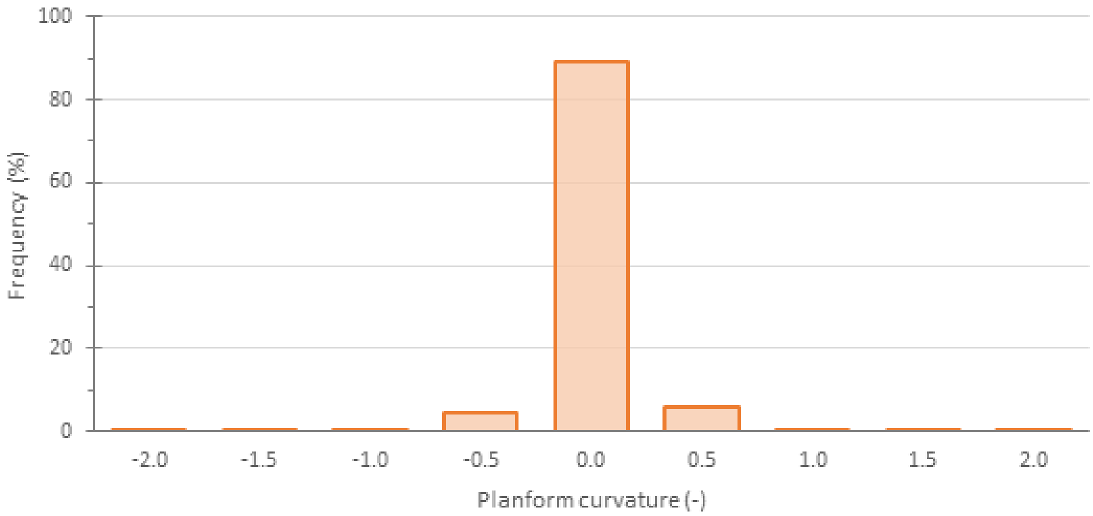

Figure 27: Distribution of at-a-point planform curvatures of the MF/AF land use points. Classes are 0.5 units wide, centred around the indicate value, e.g. the "0.0" bar refers to curvatures between -0.25 and 0.25.

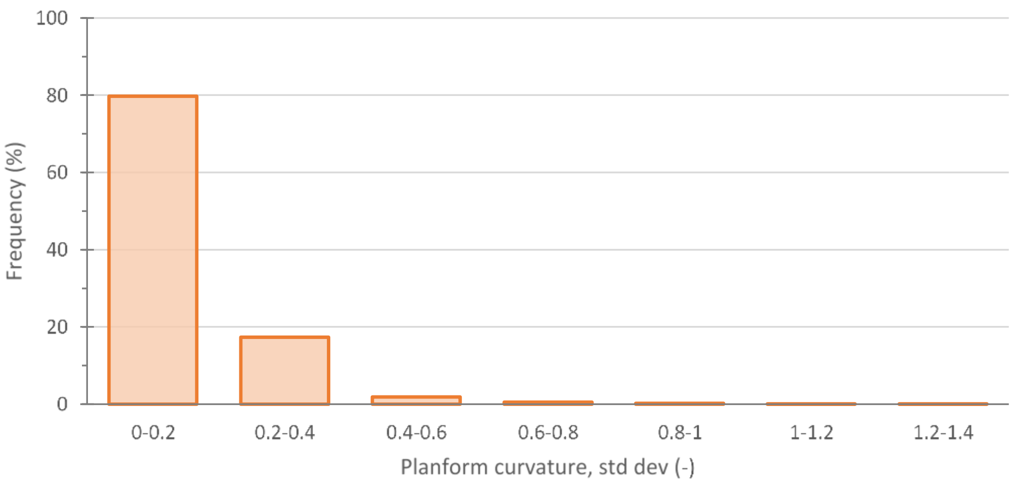

Figure 28. Distribution of standard deviations in planform curvature within a 250 m radius of the MF/AF land use points.

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Profile curvature

Profile curvature indicates how slope steepness changes in the downstream direction. Positive values indicate a decreasing downstream slope, negative values indicate a steepening of the downstream slope. Values close to zero indicate a no change in slope steepness. Distributions of profile curvatures and their standard deviations within a 250 m radius are highly similar to those of the planform curvatures (Figures 10, 11).

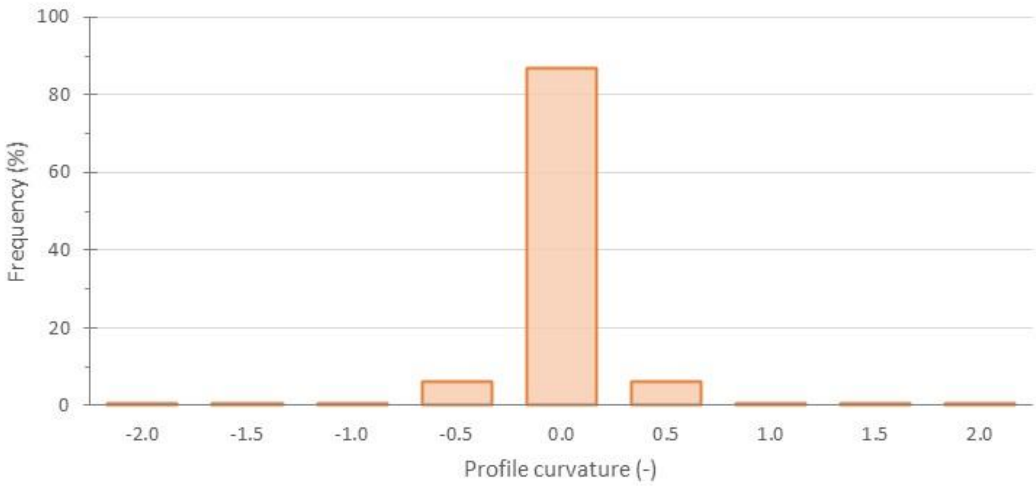

Figure 29. Distribution of at-a-point profile curvatures of the MF/AF land use points. Classes are 0.5 units wide, centred around the indicate value, e.g. the "0.0" bar refers to curvatures between -0.25 and 0.25.

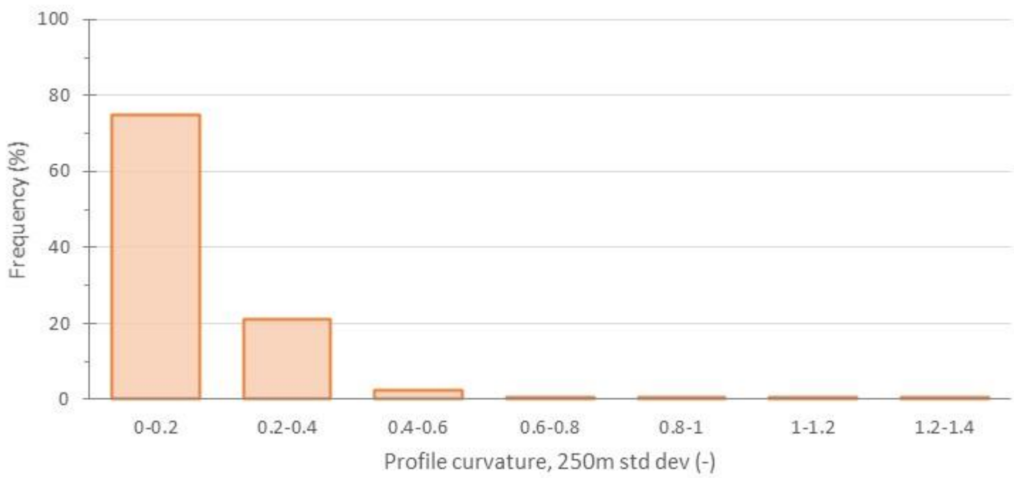

Figure 30. Distribution of standard deviations in profile curvature within a 250 m radius of the MF/AF land use points.

Summary

MF/AF land use in Europe predominantly occurs at low elevations, at gentle slopes and very low curvatures. It can occur in all aspect directions, with a slight preference for south-east facing slopes. However, these overall topographic indices might obscure differences between the various MF/AF land use types, especially

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as the statistics are heavily influenced by the dominant silvopastoral land use which comprises over 75% of all MF/AF land use (see Section 4.1.2.1). Similarly, any differences between geographic regions are equally obscured in the overall dataset. The next two sections therefore focus on analyses of topographic indices by land use (Section 4.1.2.3) and by geographic region (Section 4.1.3.4).

7.1.2.3 Topographic attributes – by land use

Elevation

There are distinct differences between elevation preferences of the MF/AF land use types (Figure 31). Elevations below 200 m are generally preferred, although elevations between 200 and 400 m are the most common for silvoarable and agrosilvopastoral land use. Overall, elevations below 400 m account for over 70% of occurrences for all MF/AF land use types except silvopastoral (45%) and silvoarable (51%). These last two land use types are more diverse in their elevation distributions, with especially silvopastoral land use covering a highly diverse elevation range (Figure 31). The same patterns exist when considering average elevations within a 250 m radius (not shown).

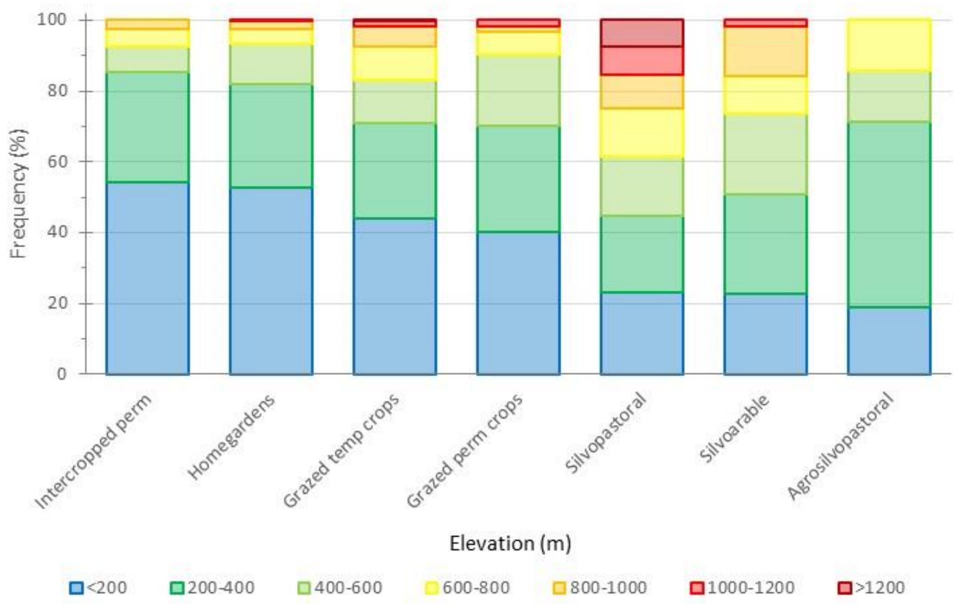

Figure 31. Distribution of at-a-point elevations for different MF/AF land use types.

The distribution of standard deviations of elevations within a 250 m radius indicates that most MF/AF land use types occur in areas with very limited variations in elevation (Figure 32). Silvoarable, agrosilvopastoral, grazed temporary crops, home gardens and intercropped permanent crops all have at least 75% occurrence in locations with less than 10 m standard deviation in elevation. Only grazed permanent crops and silvopastoral land use have over 50% of occurrences in locations with more than 10 m standard deviation in elevation. Especially silvopastoral land use is more tolerant of elevation differences and has about 17% of its occurrences in locations with more than 30 m standard deviation in elevation (Figure 32).

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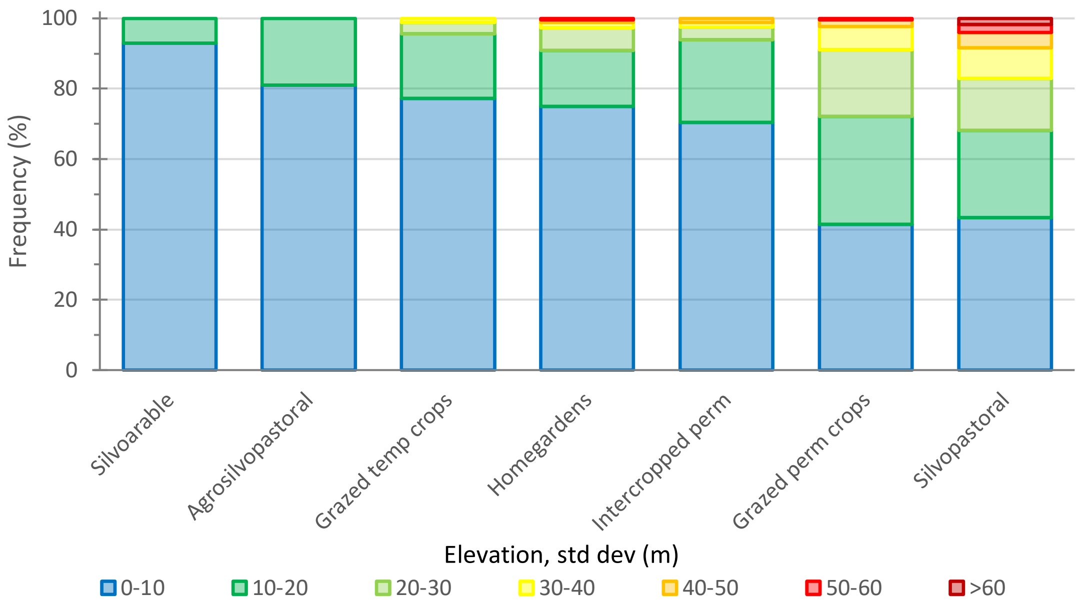

Figure 32. Distribution of standard deviations of elevations within a 250m radius, for different MF/AF land use types.

Slope

All MF/AF land use types occur most commonly on gentle slopes, i.e. less than 10 degrees – for most types even less than 5 degrees (Figure 33). However, silvopastoral land use and grazed permanent crops have at least 25% occurrence on locations with slopes greater than 10 degrees. The distributions are similar when average slopes in a 250 m radius are considered (not shown).

Silvopastoral land use and grazed permanent crops also are more tolerant for variations in slope, as standard deviations of slope within a 250 m radius frequently are between 2 and 6 degrees (not shown), whilst for other MF/AF land use types this is mostly constrained to less than 2 degrees. However, standard deviations of slope only rarely exceed 10 m, for all land use types.

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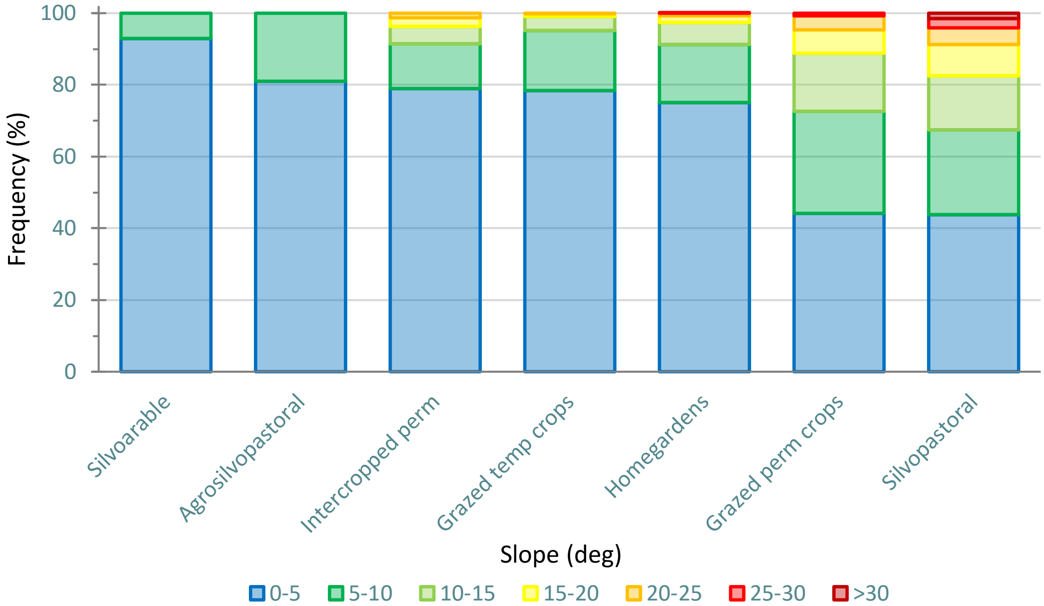

Figure 33. Distribution of at-a-point slopes for different MF/AF land use types.

Aspect

Preferential slope aspect is markedly different between the MF/AF land uses (Figure 34). Agrosilvopastoral land use shows a strong preference for south-west and north-east aspects (Figure 34A), whilst silvoarable land use seems preferentially aligned along north-west and south-east aspects (Figure 34F). Intercropped permanent crops mostly occur on south to west facing slopes (Figure 34E). Other MF/AF land uses have only minor preferences, and particularly silvopastoral land-use is nearly equally distributed in all directions (Figure 30G). It is worth noting though that the land uses that show the strongest directional preferences, i.e. agrosilvopastoral, silvoarable and intercropped land uses, are also the ones with the fewest occurrences in the LUCAS database and are also the ones that occur almost exclusively on very gentle slopes (Figure 33). Hence, these apparently strong aspect preferences likely do not represent meaningful patterns for these land uses.

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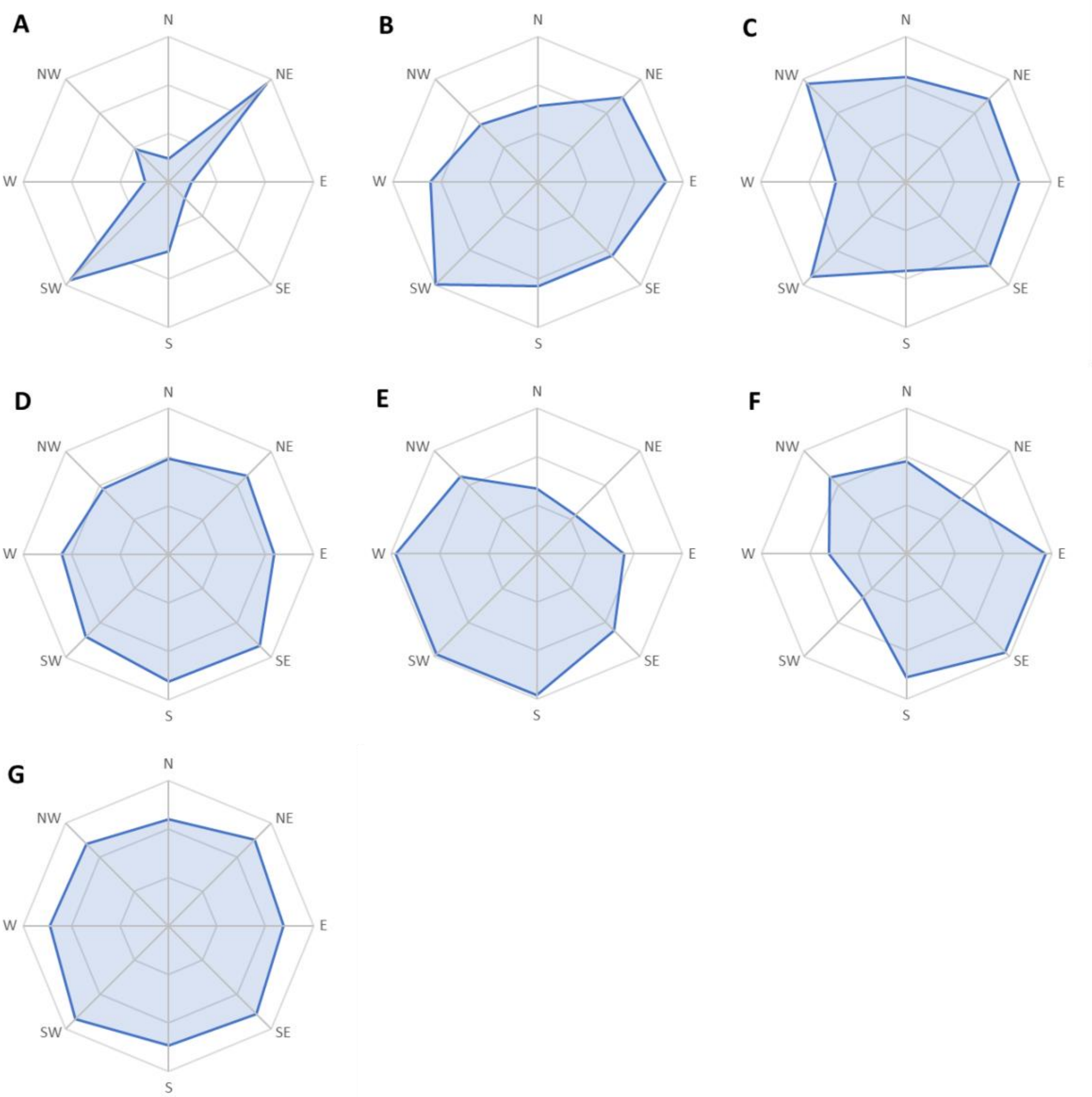

Figure 34. Distributions of at-a-point aspects for different MF/AF land use types. A: agrosilvopastoral (n=21), B: grazed permanent crops (n=304), C: grazed temporary crops (n=556), D: home gardens (n=1222), E: intercropped permanent crops (n=81), F: silvoarable (n=57), G: silvopastoral (n=7805).

When considering the majority aspect within a 250 m radius, the overall picture is similar (Figure 35), except for intercropped and silvoarable land uses (Figure 35E,F). Especially silvoarable land use has a notably different distribution of its majority aspect (Figure 35F) than its at-a-point aspects (Figure 35F). This likely is a statistical peculiarity due to the low number of datapoints (n = 57) and the predominantly gentle slopes on which silvoarable land use occurs (Figure 33), rather than being a meaningful insight in aspect preferences of this land use.

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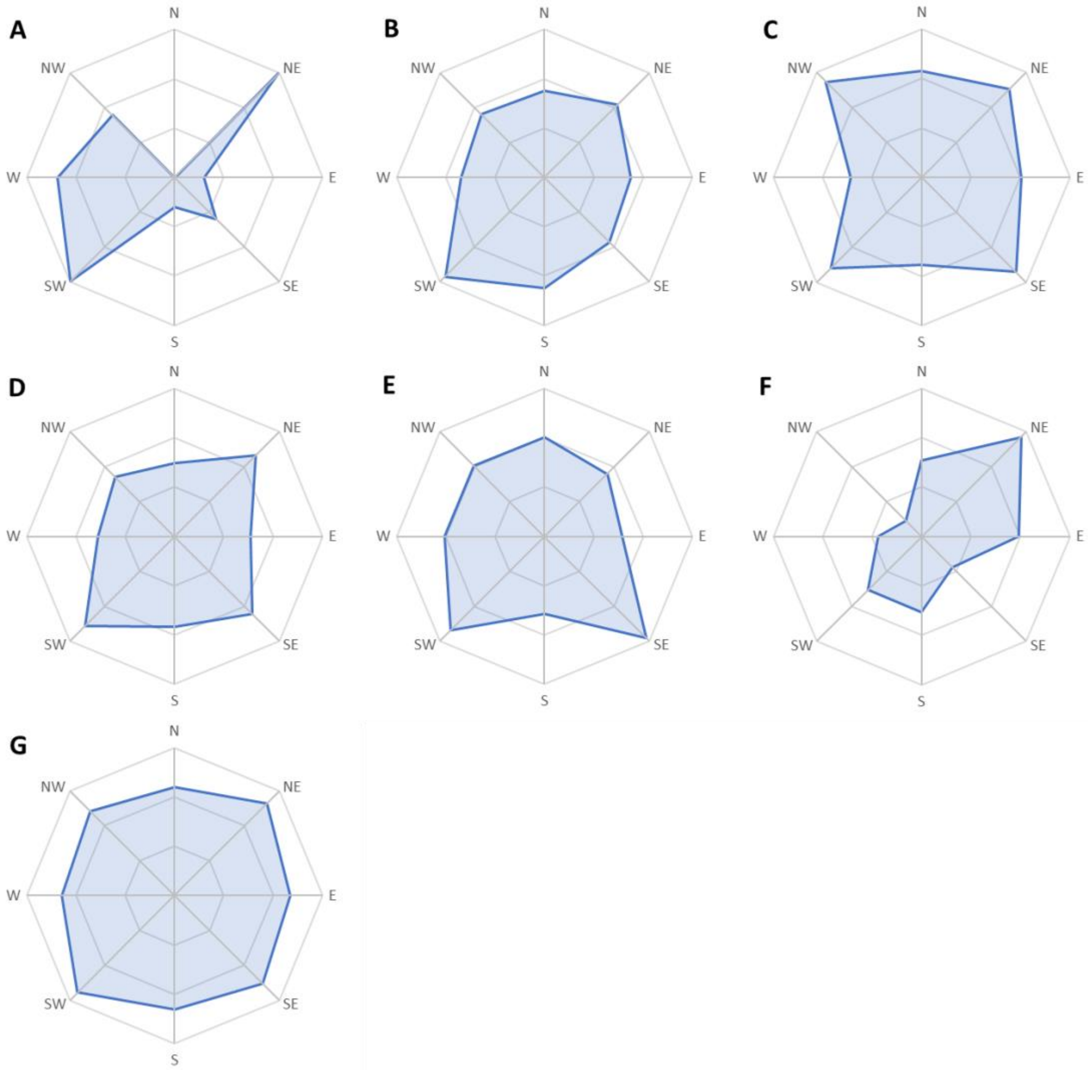

Figure 35. Distributions of majority aspects within a 250 m radius, for different MF/AF land use types. A: agrosilvopastoral (n=21), B: grazed permanent crops (n=304), C: grazed temporary crops (n=556), D: home gardens (n=1,222), E: intercropped permanent crops (n=81), F: silvoarable (n=57), G: silvopastoral (n=7,805).

Planform curvature

There are few differences between planform curvature preferences of all the MF/AF land use types (not shown), with each having a planform curvature predominantly between -0.25 and 0.25 as per the overall distribution (Figure 36). Only the variations in planform curvature within a 250 m radius are slightly greater for temporary permanent crops and silvopastoral land use, but are mainly still very small (Figure 36).

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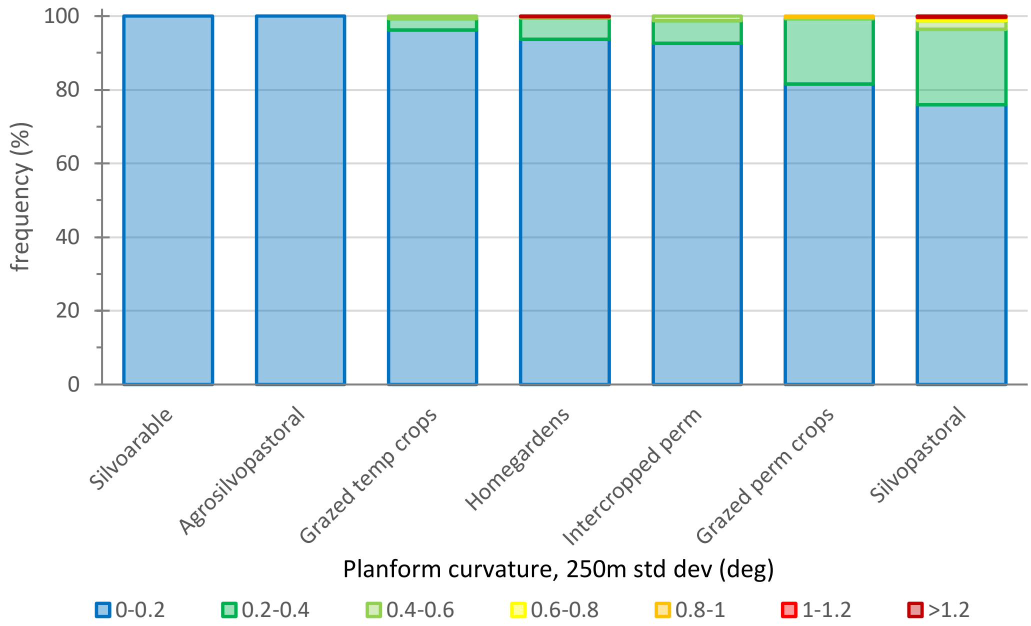

Figure 36. Distribution of standard deviations of planform curvature within a 250 m radius, for different MF/AF land uses.

Profile curvature

Distributions of profile curvatures and their standard deviations within a 250 m radius are highly similar to those of the planform curvatures. Only the distribution of standard deviations is shown here (Figure 37).

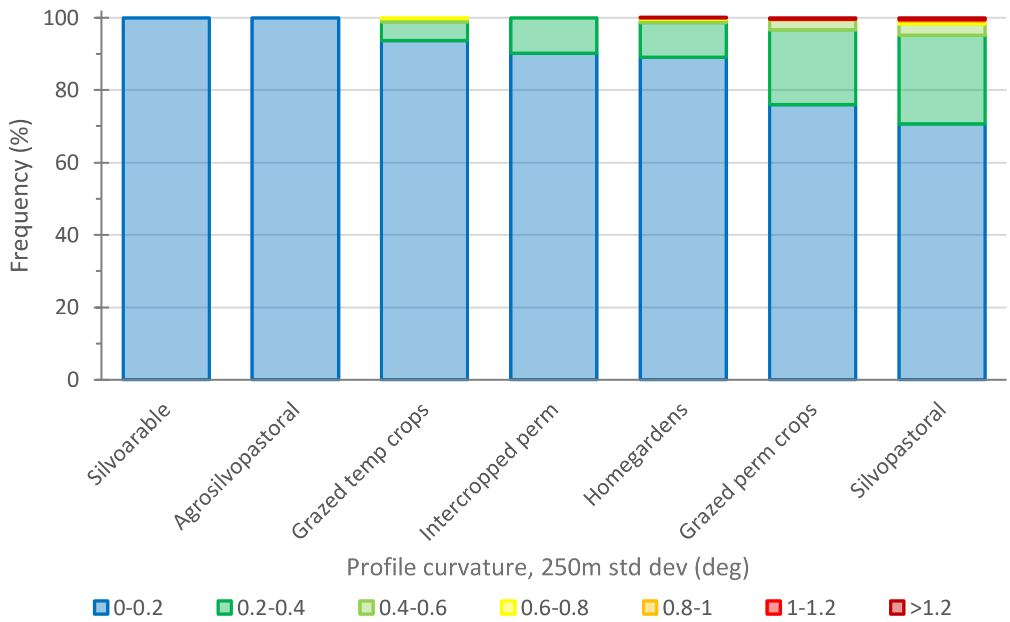

Figure 37: Distribution of standard deviations of profile curvature within a 250 m radius, for different MF/AF land uses.

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Summary

The analysis of topographic indices by land use confirms the overall trends (4.1.2.2), but shows some differences between MF/AF land use types. Silvopastoral land use stands out as the most versatile, occurring over a wider range of elevations, slope steepnesses, slope aspects and curvatures than any of the other MF/AF land use types.

7.1.2.4 Topographic indicators – by region

Elevation

The distribution of elevations at which MF/AF land use occurs is distinctly different throughout Europe (Figure 38). In Northern Europe and in UK and Ireland, the vast majority of all MF/AF land use occurs at low elevations (with respectively less than 1% and 6% occurring at elevations over 400 m), whilst Eastern Europe and especially Southern Europe having a much broader range of elevations at which MF/AF land use occurs. To a large extent these patterns reflect the distribution of topographic elevations of each region, but not exclusively so. The pattern is also strongly dominated by the unequal distribution of LUCAS points between the regions, and especially by Southern Europe having 5892 silvopastoral land use points. The regional pattern is similar for distributions of average elevations within a 250 m radius (Figure 39), albeit with some minor differences in the individual elevation distributions for each region. The standard deviations of elevations within a 250 m radius also show distinct regional differences (Figure 40), with Southern Europe again having the wider range. Somewhat surprisingly given its notable preference for low elevations, the UK and Ireland also have a higher tolerance for variability in elevation (Figure 40).

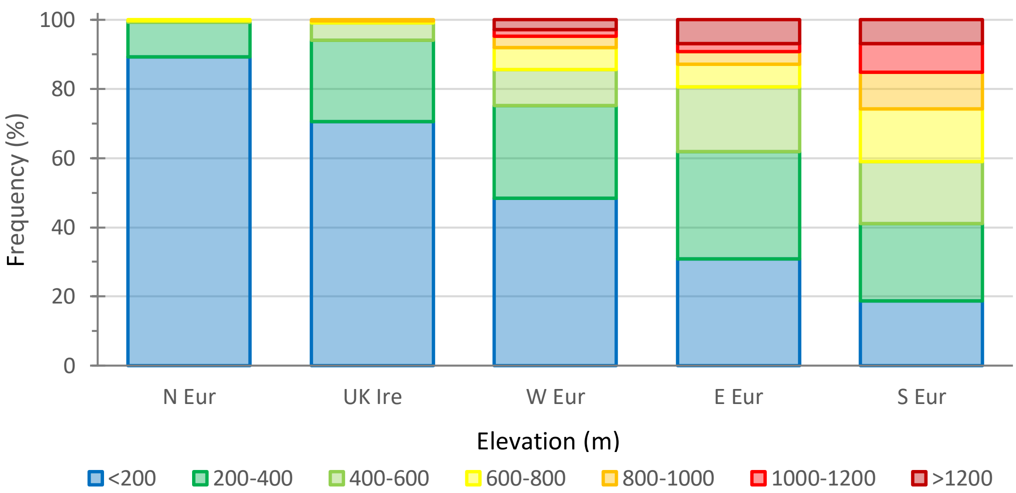

Figure 38. Distribution of at-a-point elevations for different geographic regions.

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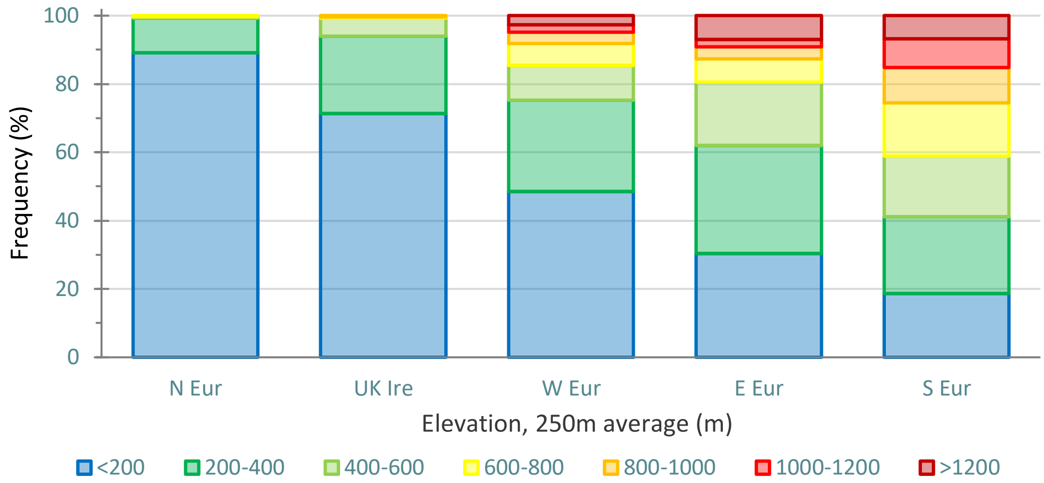

Figure 39. Distribution of average elevations within a 250 m radius for different geographic regions.

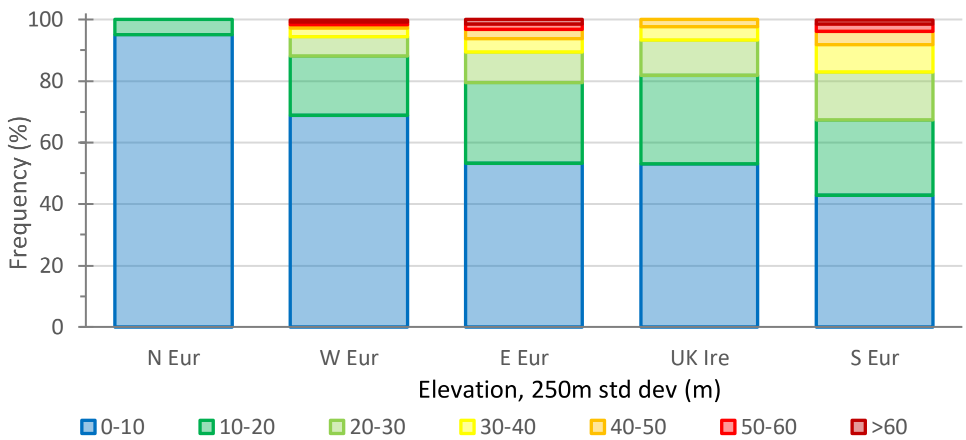

Figure 40. Distribution of standard deviations of elevation within a 250 m radius for different geographic regions.

Slope

Similar to elevation distributions, the distributions for slopes at which MF/AF land use occurs are also variable within Europe, with Eastern and Southern Europe again exhibiting the widest ranges (Figure 41). The distribution for average slopes within a 250 m radius is highly similar (not shown). The regional patterns for slope variability within a 250 m radius are more similar to each other, except for Northern Europe where slope variability is more restricted than the other regions (Figure 42).

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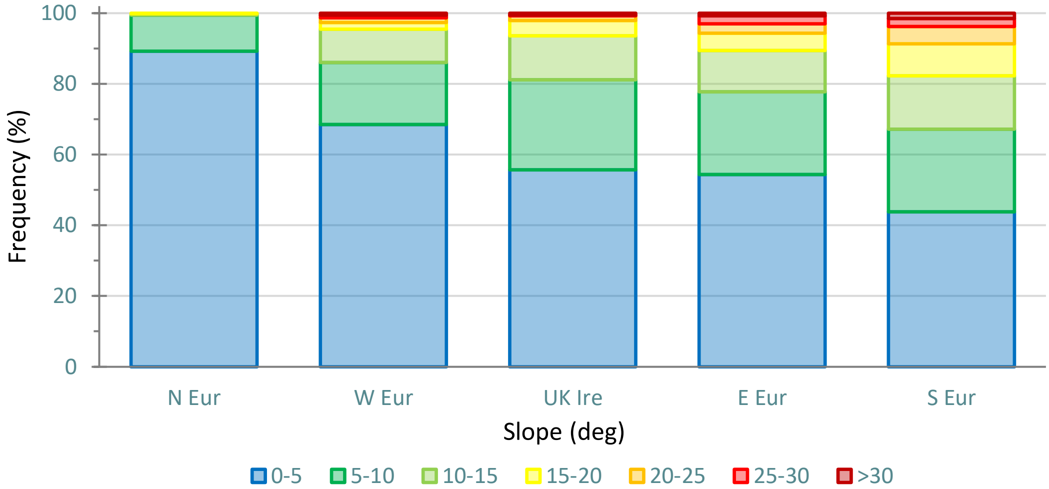

Figure 41: Distribution of at-a-point slopes for different geographic regions.

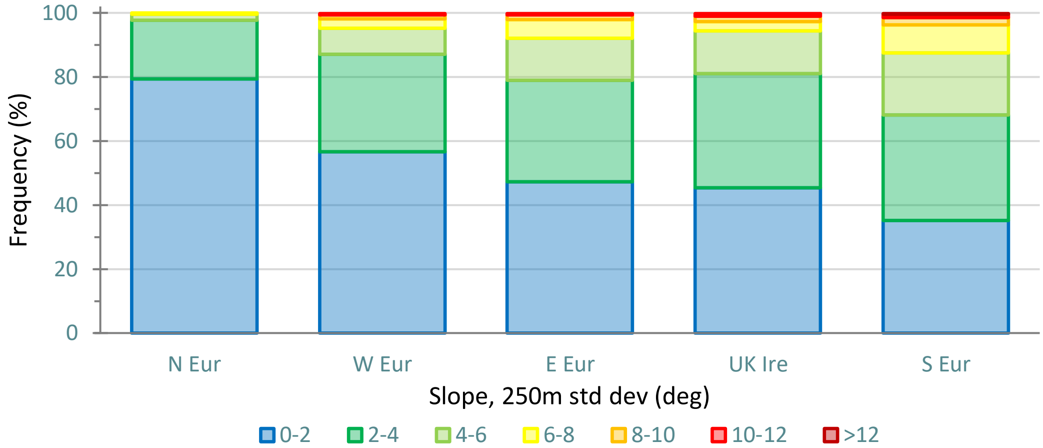

Figure 42. Distribution of standard deviations of slope within a 250 m radius for different geographic regions.

Aspect

MF/AF land use occurs on slopes facing all directions in all geographic regions, albeit with some minor regional differences in their distributions (Figure 43). In Southern Europe, all aspects are more or less equally prevalent with a small preference for southwest-facing slopes and a slight underrepresentation of north-facing slopes (Figure 25E). Both UK/Ireland and Eastern Europe exhibit a preference for southwest- to southeast facing slopes (Figure 43A,C), but the UK/Ireland has underrepresented northeast aspects whilst Southern Europe has underrepresented northwest aspects. In Northern Europe, northeast aspects are the most common, although north-facing slopes are underrepresented (Figure 43B). In Western Europe, both east- and west-facing slopes are notably underrepresented whilst all other directions are equally common.

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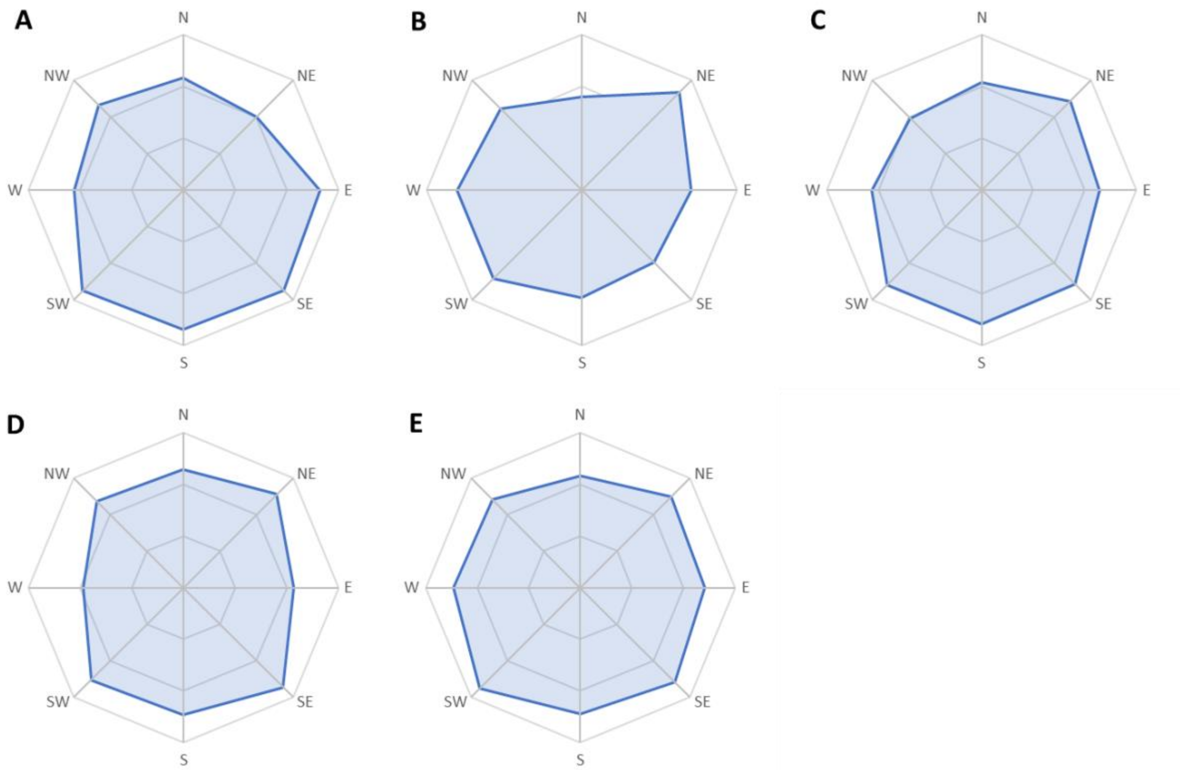

Figure 43: Distributions of at-a-point aspects for different MF/AF land use types. A: UK and Ireland (n=370), B: Northern Europe(n=555), C: Eastern Europe (n=1217), D: Western Europe (n=878), E: Southern Europe (n=7026).

Majority aspects within a 250 m radius are broadly similar to the at-a-point aspects, but some differences do exist (not shown). As per the overall aspects, cardinal directions become less prevalent in the distribution of majority aspects for all regions. Southern Europe has the most equal distribution of majority aspects. UK/Ireland also exhibits a stronger preference for intercardinal majority aspects, especially southwest and southeast. For Northern Europe and Eastern Europe southwest-facing and northeast-facing slopes are the most dominant majority aspects, whilst east- and west-facing slopes remain underrepresented in the majority aspects for Western Europe.

Planform curvature

There are no notable differences in planform curvatures between the different geographic regions (not shown), and only minor differences in the standard deviations in planform curvature, which is rarely greater than 0.4 for all regions.

Profile curvature

Similar to planform curvature, there are no notable differences in profile curvatures between the different geographic regions (not shown), and only minor differences in the standard deviations in profile curvature, which is rarely greater than 0.4 for all regions.

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Summary
There are some differences in the topographic indices of MF/AF land use between the different geographic regions, with especially Southern Europe exhibiting a higher diversity of topographies on which MF/AF land use occurs.

7.1.3 Conclusions

MF/AF land uses in Europe predominantly occur at lower elevations, at very gentle slopes and very low curvatures. Overall, there is a slight preference for south-west facing slopes.

These overall trends obscure some differences between the various MF/AF land use types. Most MF/AF land use indeed occur predominantly at low elevations, i.e. less than 400 m, although both silvopastoral and silvoarable land uses commonly occur on higher elevations as well. Especially silvopastoral land use is highly diverse, occurring over a wider range of elevations, slope steepnesses, slope aspects and curvatures than any of the other MF/AF land use types.

Furthermore, elevations and slope gradients of MF/AF systems are more frequent on steeper slopes than the complete dataset. Contrary, they are less frequent than the complete dataset at very low elevations and very low slopes.

Finally, it is notable that Southern Europe exhibits a higher versatility of topographies for MF/AF land use. However, it is not immediately obvious what the cause-and-effect are in this relation, i.e. if the higher versatility is a cause of the higher occurrence of MF/AF land use in Southern Europe, or if –conversely– the higher occurrence of MF/AF land use is expressed through a wider range of topographies on which it occurs.

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7.2 Climate characteristics of MF/AF systems

7.2.1 Introduction

Since climate is one the main environmental factors influencing and controlling agricultural activities, particularly for its relevance in the context of climate change, an analysis of the climatic characteristics is presented in this section for the regions and land uses of interest in the AGROMIX project.

The area of interest covers all EU countries plus United Kingdom. For methodological interest, as described below, and to provide sense to the analysis, the studied regions have been integrated into biogeographical regions covering all Europe, and the land use classes attended are those defined in chapter 2 and data analysed is based on the LUCAS database of survey year 2018.

7.2.2 Methods

7.2.2.1 Dataset characteristics and climate indicators

Data used in this section originally comes from the C3S Global Agriculture project, a service of the Copernicus programme intended to provide better understanding and management of climate risks in climate-sensitive sectors such as agriculture. The C3S Sectorial Information System (SIS) provides data, tools, and information in supporting public and private sectors in those climate-related issues (https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-agroclimatic-indicators?tab=overview).

Agroclimatic indicators are provided in this project at global scale, from which EU countries were extracted, and reflect climate variability and change in a meaningful manner for the agricultural sector. The indicators consist of a series of precomputed variables, of common interest, based on formulas that measure climatic factors and conditions that might positively or negatively affect vegetation or correlate to some types of vegetation in the areas under interest. In this section just generic agroclimatic indicators are provided that basically consist on aggregation, accumulation or occurrence indicators calculated as a function of particular atmospheric variables such as temperature or precipitation.

Bias-corrected climate datasets provided through the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP 0) have been used as input data to calculate the agroclimatic indicators for historical and future time periods. As a proxy for historical observations, the “Watch Forcing Data methodology applied to ERA-Interim” (WFDEI) were used to generate the observational historical agroclimatic indicators used herein.

C3S Global Agriculture SIS delivers 26 generic agroclimatic indicators from which only those showing annual mean values were considered. All indicators are computed from realizations of daily data, derived from two essential climate variables: Surface air temperature (daily minimum, TN; maximum, TX; and mean temperature, TG) and precipitation (daily total precipitation, RR). For calculation purposes, daily data were aggregated to “dekads” (10-days periods), from which annual means were calculated when necessary. The

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indicators were therefore calculated as seasonal or dekadal resolution (10-day period). In the case of dekadal data, 36.5 dekads were considered for each year in order to obtain annual values.

The dataset is distributed as NetCDF-4 file format available at 0.5˚x 0.5˚ lat-long grid over the global land area (approx. 55.5 km x 55.5 km at equator). The historical dataset covers the period from 1951 to 2005. For this section, five agroclimatic indicators were selected. The acronym, short description, general application and units of each indicator is reflected in Table 27. All the indicators originally expressed in the database as K (Kelvin) units were transformed to the Celsius scale (T˚C = TK – 273.15).

Table 27. List of agroclimatic indicators with the used acronym, the general description, and the use in agriscience.

Acronym	Description	Application	Units
DTR	Mean of Diurnal Temperature Range	Provides information on climate variability and change. Also serves as a proxy for information on the clarity (transmittance) of the atmosphere	°C
RR	Precipitation sum	Provides information on possible water shortage or excess.	mm
TG	Mean of daily mean temperature	Provides information on long-term climate variability and change	°C
TN	Mean of daily minimum temperature	Provides information on long-term climate variability and change	°C
TX	Mean of daily maximum temperature	Provides information on long-term climate variability and change	°C

The algorithms used for the computation of each indicator are extracted from: https://datastore.copernicus-climate.eu/documents/sis-global-agriculture/C3S422Lot1.WEnR.DS1_ATBD_v2.1.pdf) and are presented below:

- ✓ **Precipitation sum (RR)**

Let RR_{ij} be the daily precipitation amount for day *i* of period *j*. Then sum values are given by:

$$RR_j = \sum_{i=1}^{I} RR_{ij}$$

- ✓ **Mean of daily mean temperature (TG)**

Let TG_{ij} be the mean temperature at day *i* of period *j*. Then mean values in period j are given by:

$$TG_j = \frac{\sum_{i=1}^{I} TG_{ij}}{I}$$

- ✓ **Mean of daily minimum temperature (TN)**

Let TN_{ij} be the minimum temperature at day *i* of period *j*. Then mean values in period *j* are given by:

$$TN_j = \frac{\sum_{i=1}^{I} TN_{ij}}{I}$$

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- ✓ **Mean of daily maximum temperature (TX)**

Let TX_{ij} be the maximum temperature at day *i* of period j. Then mean values in period *j* are given by:

$$TX_j = \frac{\sum_{i=1}^{I} TX_{ij}}{I}$$

- ✓ **Mean of Diurnal Temperature Range (DTR)**

Let *TXij* and *TNij* be the daily maximum and minimum temperature at day *i* of period *j*, then the mean diurnal temperature range in period *j* is:

$$DTR_j = \frac{\sum_{i=1}^{I}(TX_{ij} - TN_{ij})}{I}$$

7.2.2.2 Land use data and geographical climatic data sampling

Land use data was derived from the LUCAS 2018 dataset (see chapter 2), using only those points representing MF/AF systems (n=10,040), at European scale (EU-27 and the United Kingdom). Due to the scarcity of agrosilvopastoral points included in the LUCAS database, this class was assigned to silvospastoral land use, so that six types of MF/AF systems were considered for the climatic characterization: silvopastoral, silvoarable, grazed arable crops, grazed permanent crops, intercropped permanent crops and home gardens.

By means of a GIS, values of the climatic indicators contained on NetCDF-4 data files at 0.5˚ x 0.5˚ lat-long grid (Figure 44 to Figure 46 and Annex 7, 8) were consulted and extracted for the selected LUCAS points.

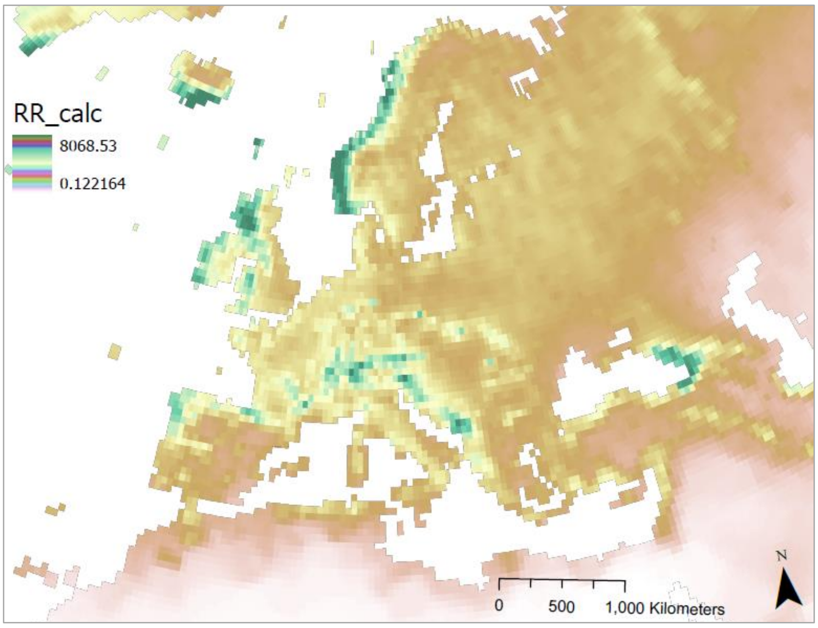

Figure 44. Annual total precipitation (mm). Note: Values represent the annual sum of dekadal (10 days) total precipitation.

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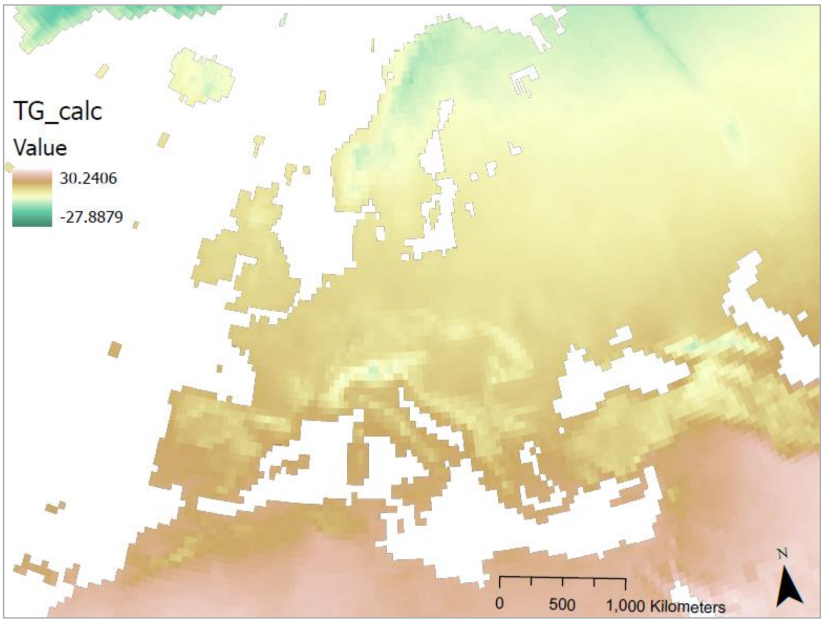

Figure 45. Annual mean temperature (°C). Note: Values represent the mean of dekadal (10 days) mean temperature.

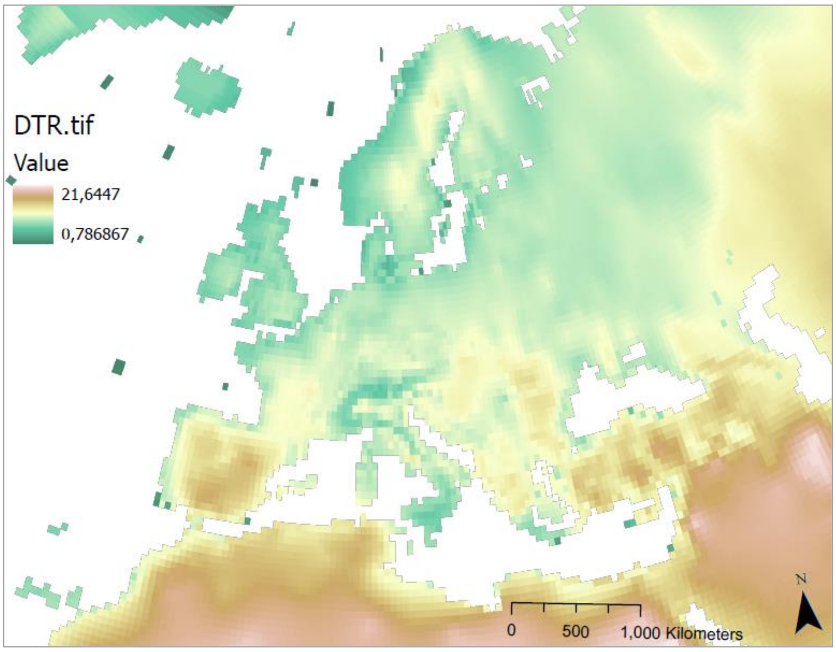

Figure 46. Mean of diurnal temperature range (°C). Note: Values represent the mean of dekadal (10 days) mean diurnal temperature range.

7.2.2.3 Data analysis

The regionalization of the LUCAS and climate indicators data and the presentation of the results was made attending, first, to its overall distribution over EU-28. A second regionalization was made attending to the EU biogeographical regions where LUCAS land use points were present. For this, the biogeographical regions dataset of Europe was used (Figure 12), that contains the official delineations used in the Habitats Directive

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(92/43/EEC) and for the EMERALD Network set up under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) (https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3).

When presenting the results, the 5 climatic indicators selected were explained, as they are considered the most relevant for characterizing the main climatic characteristics of the land uses and regions. Several general statistics were computed in this step of the analysis that are explained by regions and land uses.

To describe the climatic differences that could occur between regions and land uses, particularly between those land uses shared by different biogeographical regions, the non-parametric analysis of variance (Kruskal-Wallis) and the median test were performed and represented as box and whisker plots.

7.2.3 Results

7.2.3.1 Overall climatic indicators

Table 28 summarizes the main statistics of the selected climatic indicators of the dataset (MF/AF data points) and are described briefly in the following section.

Table 28. Statistics of the agroclimatic indicators of MF/AF data points. StdDev – standard deviation, CoefVar – coefficient of variation.

Indicator	Mean	Median	Minimum	Maximum	Variance	StdDev	CoefVar
Precipitation sum (mm)	22.6	21.1	0.0	66.2	55.4	7.4	32.9
Temperature mean (°C)	9.7	9.8	-4.8	19.7	16.7	4.1	42.0
Temperature min (°C)	5.4	5.7	-8.6	16.1	15.3	3.9	72.2
Temperature max (°C)	14.2	14.0	-1.4	26.3	20.9	4.6	32.3
Diurnal temperature range (°C)	8.8	8.6	0.0	13.5	2.7	1.6	18.6

7.2.3.2 Precipitation sum (RR, mm)

Precipitation sum by biogeographical regions

Mean dekadal precipitation for all the biogeographical regions amounted to 22.6 mm (Table 28). The maximum value was found in the Alpine region with 28.8 mm, followed by the Atlantic region with 27.4 mm (Table 29; Figure 47). As for the lower values, the bioregion showing the minimum mean precipitation was the Steppic, which reported a mean of 15.2 mm, followed by the Black Sea, with 15.7 mm.

Regarding the variability of this climate indicator, the Mediterranean region reported the highest coefficient of variation, with 34.8%, being the lowest value observed in the Steppic region with 7.3% (Table 29). However, the Alpine region showed a greater variance (84.3 mm), with a high interquartile range (13.6 mm) (Figure 48).

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Precipitation of the analysed LUCAS points was significantly different among many of the MF/AF points grouped according biogeographical regions, except for the Alpine with Atlantic regions and the Black Sea with Pannonian and Steppic regions, that showed similar median values (Figure 48).

Table 29. Statistics of precipitation sum by biogeographical regions for MF/AF systems. N – number of points, M_year – mean of annual total, Min. – minimum value, Max. – maximum value, Lower Q – lower quartile, Upper Q – upper quartile, Var – cariance, StDev – ctandard deviation, CoVar – coefficient of variation.

Bioregion	N	Mean	*M_year*	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Alpine	850	28.8	*1051*	26.9	12.3	64.8	21.9	35.5	84.3	9.2	31.9
Atlantic	2005	27.4	*1000*	25.2	0.0	66.2	22.7	29.9	56.3	7.5	27.4
Black Sea	32	15.7	*573*	16.6	8.9	19.1	13.3	17.2	7.2	2.7	17.1
Boreal	1691	19.6	*715*	19.5	0.0	30.9	18.1	20.9	6.5	2.5	13.0
Continental	2804	23.2	*858*	21.7	14.0	64.8	18.1	26.5	42.7	6.5	28.2
Mediterranean	2351	18.7	*683*	17.1	0.0	53.5	14.1	22.8	42.6	6.5	34.8
Pannonian	240	17.6	*642*	17.4	15.3	22.5	16.4	18.7	2.2	1.5	8.5
Steppic	67	15.2	*555*	15.1	13.3	17.9	14.3	15.6	1.2	1.1	7.3

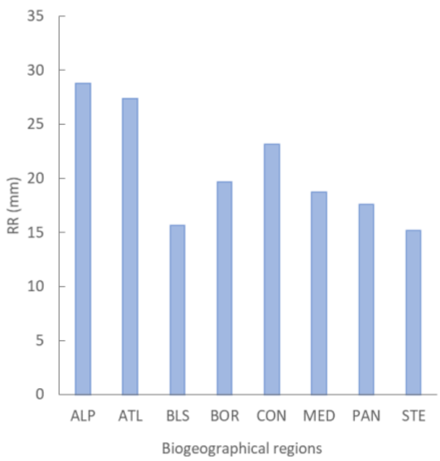

Figure 47. Mean values of precipitation sum over 10 days by biogeographical regions.

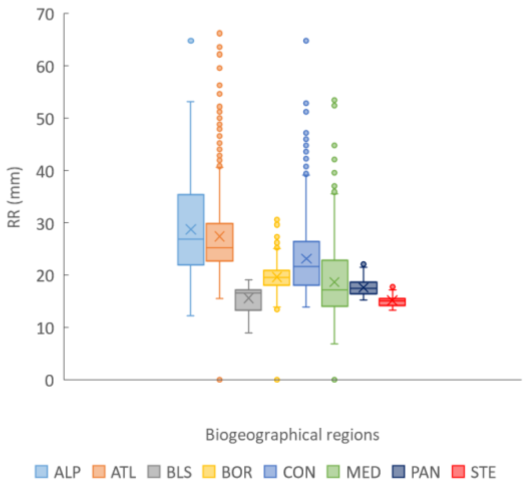

Figure 48. Box and whisker plots for precipitation sum in 10 days by biogeographical regions.

Precipitation sum by land use type

When the precipitation sum in 10 days was analysed for the different MF/AF systems, the reported values showed an even distribution in comparison to the pattern explained when regionalised by biogeographical regions. The difference between the maximum and minimum mean values was only 2.4 mm, observed between the intercropped permanent crops and silvoarable land uses, respectively (Table 30). The same trend was observed with median values, which did not show significant differences among land use types (Figure 49).

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

Table 30. Statistics of precipitation sum for MF/AF systems. PC – permanent crops, N – number of points, Min – minimum, Max – maximum, Lower Q – lower quartile, Upper Q – upper quartile, Var – variance, StDev – standard deviation, CoVar – coefficient of variation.

Land Use	N	Mean	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Grazed arable crops	556	23.1	21.6	0.0	64.8	17.9	26.4	64.2	8.0	34.6
Grazed PC	304	22.2	20.7	0.0	52.8	17.4	25.2	56.1	7.5	33.8
Home gardens	1220	22.7	21.0	0.0	63.6	17.7	26.2	55.5	7.5	32.8
Intercropped PC	81	23.4	21.1	11.2	66.2	18.2	25.2	69.9	8.4	35.8
Silvoarable	57	21.0	18.6	13.8	43.8	17.1	22.6	41.3	6.4	30.6
Silvopastoral	7822	22.6	21.1	0.0	64.8	17.7	25.9	54.7	7.4	32.7

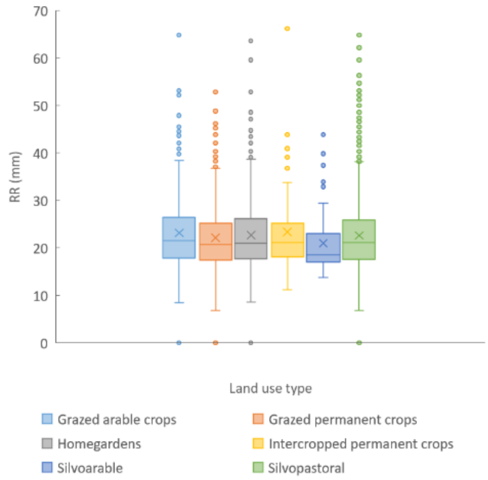

Figure 49. Box and whisker plots for the values of precipitation sum in 10 days by land use type.

Mean of daily mean temperatures (TG, °C)

Mean of daily mean temperatures by biogeographical region

Table 31 shows the main statistical values of the means of daily mean temperature for all biogeographical regions. The mean value for the entire dataset was 9.7 °C (Table 28), corresponding the maximum mean value to the Mediterranean region, with 14.5 °C, and the minimum to the Boreal region, with 4.6°C (Table 31). Nonetheless, the variability was higher in the Alpine region, where the minimum value of mean temperature was -4.8°C and the maximum value was 14.9°C, with a coefficient of variation of 78.5%. This is due to the topographic conditions, being the temperatures in Alpine areas strongly determined by altitude. As shown in Figure 50, the median values were significantly different amongst nearly all the biogeographical regions for this climatic indicator, except the Black Sea, that reported similar median values as Mediterranean and Steppic regions. Also similar were Atlantic and Pannonian, and Pannonian and Steppic bioregions.

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Table 31. Statistics of mean daily mean temperatures by biogeographical regions. N – number of points, Min. – minimum value, Max. – maximum value, Lower Q – lower quartile, Upper Q – upper quartile, Var – variance, StDev – standard deviation, CoVar – coefficient of variation.

Bioregion	N	Mean	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Alpine	850	5.1	5.8	-4.8	14.9	2.3	8.1	16.1	4.0	78.5
Atlantic	2005	10.4	10.2	0.0	15.5	9.4	11.5	2.9	1.7	16.4
Black Sea	32	12.4	12.5	11.5	13.3	12.0	12.9	0.4	0.6	4.9
Boreal	1691	4.6	5.1	-2.5	7.9	3.3	6.4	5.1	2.3	49.2
Continental	2804	9.6	9.4	3.9	14.4	8.5	10.6	2.3	1.5	15.9
Mediterranean	2351	14.5	14.9	0.0	19.7	12.7	16.3	6.5	2.5	17.6
Pannonian	240	10.6	10.7	6.8	12.1	10.3	11.0	0.5	0.7	6.6
Steppic	67	11.1	11.2	9.8	11.8	10.6	11.6	0.3	0.6	5.1

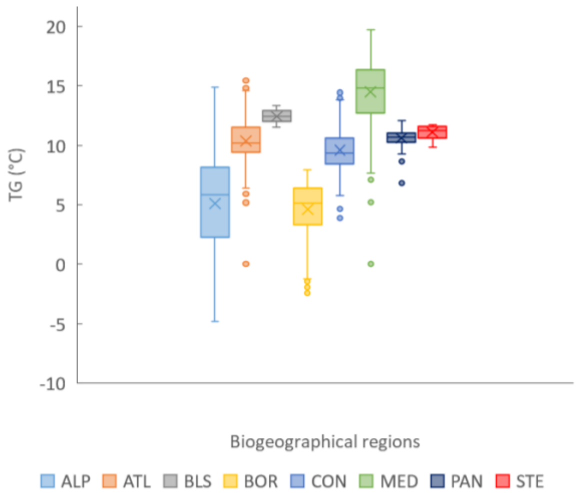

Figure 50. Box and whisker plots for the means of daily mean temperature by biogeographical regions.

Mean of daily mean temperature by land use type

The minimum value obtained for the means of daily mean temperature was observed for the points of intercropped permanent crops with 9.1°C, and the maximum value corresponds to grazed permanent crops and home gardens, with 9.8°C (Table 32). Nevertheless, when the land uses were analysed all over the EU region, mean temperatures did not show significant differences among them (not shown).

Table 32. Mean of daily mean temperatures by MF/AF type. PC – permanent crops, N – number of points, Min – minimum, Max – maximum, Lower Q – lower quartile, Upper Q – upper quartile, Var – variance, StDev – standard deviation, CoVar – coefficient of variation.

Land Use	N	Mean	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Grazed arable crops	556	9.7	9.8	-4.8	19.7	7.6	12.0	17.0	4.1	42.4
Grazed PC	304	9.8	9.7	-3.3	19.7	7.2	12.6	19.5	4.4	45.3
Home gardens	1220	9.8	9.8	-3.8	18.7	8.1	11.9	14.4	3.8	38.7
Intercropped PC	81	9.1	9.2	-0.7	17.6	7.1	11.0	13.4	3.7	40.1
Silvoarable	57	9.3	9.9	-1.3	18.5	6.5	11.9	26.0	5.1	55.1
Silvopastoral	7822	9.7	9.8	-4.8	19.7	7.6	11.9	16.9	4.1	42.2

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7.2.3.3 Mean of daily minimum temperature (TN, °C)

Mean of daily minimum temperature by biogeographical region

With regard to the mean of daily minimum temperatures, the average value of the entire dataset amounted to 5.4°C (Table 28), being the minimum registered in Boreal and Alpine regions with 0.5°C and 1°C respectively. Both regions also showed high coefficients of variation that for the former was 403.9% (Table 33), showing a range of variation of 19.6°C and a standard deviation of 3.9°C. When comparing median values (Figure 51), most of the biogeographical regions showed significant differences among them, except for the Mediterranean with the Black Sea, Continental with Pannonian, Atlantic with Steppic and Pannonian with Steppic.

Table 33. Mean of daily minimum temperature values by biogeographical regions for MF/AF systems. N – number of points, Min. – minimum value, Max. – maximum value, Lower Q – lower quartile, Upper Q – upper quartile, Var – variance, StDev – standard deviation, CoVar – coefficient of variation.

Bioregion	N	Mean	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Alpine	850	1.0	1.6	-8.6	11.0	-0.9	3.5	15.0	3.9	403.9
Atlantic	2005	6.6	6.5	0.0	11.5	5.8	7.5	2.1	1.4	21.6
Black Sea	32	8.4	8.2	7.5	9.3	7.8	9.0	0.5	0.7	8.1
Boreal	1691	0.5	1.2	-7.3	5.6	-1.1	2.5	6.7	2.6	498.7
Continental	2804	5.3	5.2	0.3	10.3	4.3	6.2	2.2	1.5	28.0
Mediterranean	2351	9.6	9.7	0.0	16.1	7.6	11.6	7.5	2.7	28.6
Pannonian	240	5.7	5.7	1.9	7.6	5.3	6.1	0.7	0.8	14.8
Steppic	67	6.2	6.2	4.5	7.7	5.9	6.7	0.5	0.7	11.0

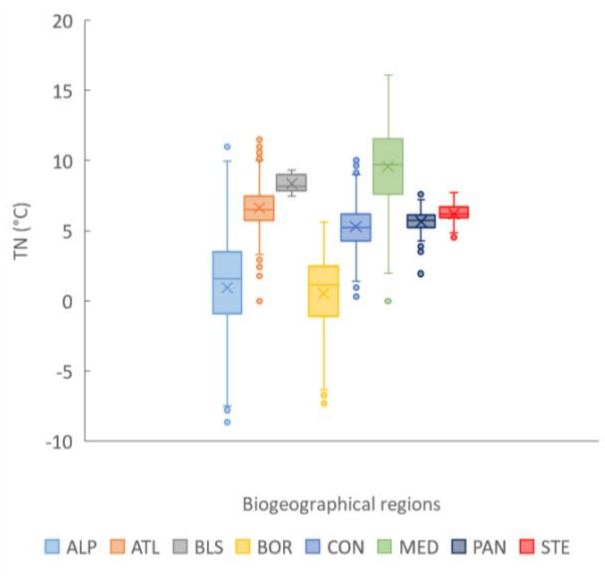

Figure 51. Box and whisker plots for daily minimum temperatures by biogeographical regions.

Mean of daily minimum temperature by land use type

As observed for previous climatic indicators, mean minimum temperatures of the different LUCAS classes studied did not show significant differences between them (Table 34). All the land uses showed minimum values ranging from -3.7°C to -8.6°C, corresponding the lower value to intercropped permanent crops and the higher value to grazed arable crops and silvopastoral points (Table 34). Maximum values ranged from 12.4°C in the intercropped permanent crops to 16.1°C of silvopastoral points, being the latter one the land use retrieving the largest differences between highest and lowest values of daily minimum temperatures. All land uses showed high coefficients of variation. No significant differences of the median between the groups were observed.

Table 34. Mean of daily minimum temperature values by land use for agroforestry and mixed systems. PC – permanent crops, N – number of points, Min – minimum, Max – maximum, Lower Q – lower quartile, Upper Q – upper quartile, Var – variance, StDev – standard deviation, CoVar – coefficient of variation.

Land Use	N	Mean	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Grazed arable crops	556	5.4	5.7	-8.6	14.8	3.6	7.7	15.8	4.0	73.8
Grazed perm crops	304	5.5	5.8	-7.5	14.8	3.1	8.2	17.8	4.2	77.0
Home gardens	1220	5.5	5.7	-7.8	15.2	3.8	7.5	13.2	3.6	66.6
Intercropped perm	81	4.9	4.9	-3.7	12.4	3.1	6.7	12.0	3.5	70.9
Silvoarable	57	5.0	5.6	-6.4	13.7	2.6	7.7	23.7	4.9	97.6
Silvopastoral	7822	5.4	5.7	-8.6	16.1	3.5	7.5	15.4	3.9	72.5

7.2.3.4 Mean of daily maximum temperature (TX, °C)

Mean of daily maximum temperature by biogeographical region

The mean of the maximum temperatures was 14.2°C for the entire dataset (Table 28). MF/AF systems in the Mediterranean region offered the highest value (20.3°C) (Table 35). The lowest mean value of maximum temperatures was observed in the Boreal (8.8°C) and Alpine (10.4°C) regions. The Alpine region also showed a significant variability if compared to other regions, with a coefficient of variation of 46.8% (Table 35). Black Sea, Pannonian and Steppic regions did not show significant differences of median values for maximum temperatures (Figure 52). The rest of the bioregions had median values that were significantly different.

Table 35. Mean of daily maximum temperatures by biogeographical regions for MF/AF systems. N – number of points, Min – minimum, Max – maximum, Lower Q – lower quartile, Upper Q – upper quartile, Var – variance, StDev – standard deviation, CoVar – coefficient of variation.

Bioregion	N	Mean	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Alpine	850	9.4	10.4	-1.4	20.2	5.5	12.8	19.1	4.4	46.8
Atlantic	2005	14.3	14.1	0.0	20.2	13.1	15.7	4.7	2.2	15.2
Black Sea	32	16.8	16.9	15.7	17.6	16.3	17.2	0.4	0.7	3.9
Boreal	1691	8.5	8.8	0.0	11.5	7.3	10.2	4.1	2.0	24.0
Continental	2804	14.0	13.7	7.5	19.1	12.6	15.2	3.3	1.8	13.0
Mediterranean	2351	19.8	20.3	0.0	26.3	18.1	21.7	7.7	2.8	14.0
Pannonian	240	15.5	15.6	11.5	16.6	15.1	15.9	0.5	0.7	4.5
Steppic	67	16.1	15.8	14.9	17.4	15.7	16.7	0.5	0.7	4.3

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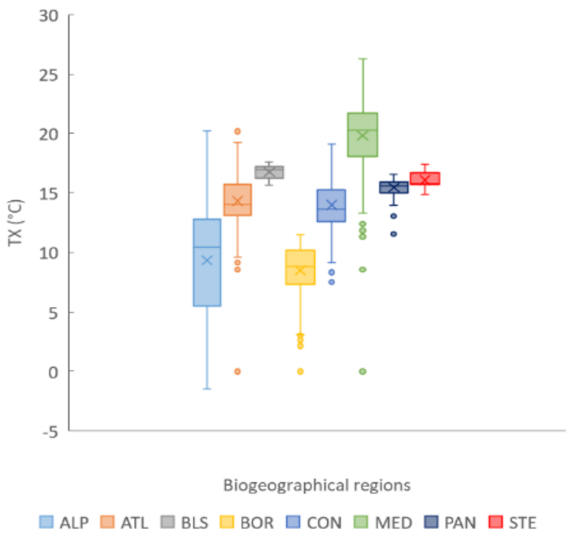

Figure 52. Box and whisker plots for daily maximum temperatures by biogeographical regions.

Mean of daily maximum temperature by land use type

According to the MF/AF classes, the studied LUCAS points did not show significant differences with respect to their mean maximum temperatures. The mean of daily maximum values varied from 13.5°C to 14.2. Just silvoarable points reported higher variability in comparison to other uses but, in general, the interquartile range was quite similar (Table 36). No significant differences were found between land use groups.

Table 36. Mean of daily maximum temperatures by land use for agroforestry and mixed systems. PC – permanent crops, N – number of points, Min – minimum, Max – maximum, Lower Q – lower quartile, Upper Q – upper quartile, Var – variance, StDev – standard deviation, CoVar – coefficient of variation.

Land Use	N	Mean	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Grazed arable crops	556	14.2	14.0	-1.3	26.3	11.6	17.1	21.0	4.6	32.3
Grazed perm crops	304	14.2	14.0	0.0	26.3	11.3	17.5	24.6	5.0	35.0
Home gardens	1220	14.2	14.1	-0.5	24.6	12.0	16.9	18.1	4.3	29.9
Intercropped perm	81	13.5	13.3	2.3	24.3	10.9	15.6	16.9	4.1	30.6
Silvoarable	57	13.6	13.7	3.6	24.6	9.6	17.3	31.6	5.6	41.3
Silvopastoral	7822	14.2	14.0	-1.4	26.3	11.5	16.9	21.2	4.6	32.5

7.2.3.5 Mean of diurnal temperature range (DTR, °C)

Mean of diurnal temperature range by biogeographical region

Regions showing high mean diurnal temperature ranges were the Mediterranean (10.3°C), Steppic (9.9°C) and Pannonian (9.8°C) while Atlantic showed the lowest (7.7°C) (Table 37). In terms of variability, Alpine and Mediterranean regions showed the highest coefficient of variation and interquartile range (Table 37). Attending median values of diurnal range of temperatures, presented in Figure 53, the bioregions can be grouped in terms of the differences observed: Alpine with Black Sea, Boreal and, particularly, Atlantic regions,

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did not show strong differences among them and showed low values as compared to Mediterranean, Pannonian and Steppic regions, of relatively higher values.

Table 37. Statistics of mean diurnal temperature ranges by biogeographical regions for agroforestry and mixed systems.

Bioregion	N	Mean	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Alpine	850	8.4	8.5	5.2	11.7	7.2	9.6	2.0	1.4	**17.0**
Atlantic	2005	7.7	7.6	0.0	10.9	6.9	8.3	1.4	1.2	15.3
Black Sea	32	8.4	8.3	7.8	9.1	8.2	8.6	0.1	0.4	4.3
Boreal	1691	8.0	8.0	0.0	11.0	7.5	8.5	0.8	0.9	11.5
Continental	2804	8.7	8.7	4.3	11.6	8.1	9.3	1.2	1.1	12.7
Mediterranean	2351	10.3	**10.3**	0.0	13.5	9.0	11.6	3.4	1.8	**18.0**
Pannonian	240	9.8	9.9	8.1	10.8	9.4	10.3	0.3	0.5	5.5
Steppic	67	9.9	9.8	8.2	11.4	9.4	10.2	0.5	0.7	7.4

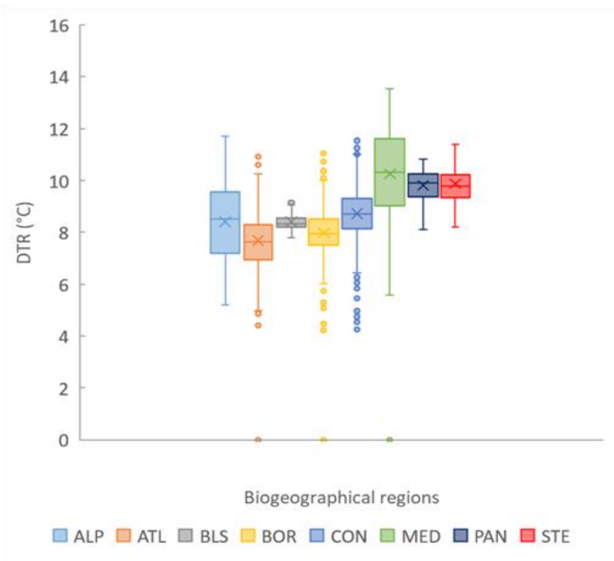

Figure 53. Median of diurnal temperature range by biogeographical regions.

Mean of diurnal temperature range by land use type

Most of the different MF/AF classes considered in this study showed very similar mean and median values of diurnal temperature ranges, that also varied little, with low coefficients of variation and interquartile ranges (Table 38). Furthermore, no significant differences among them could be detected. Nevertheless, if maximum and minimum values are considered, differences of 13.5°C are observed in diurnal ranges for Home gardens, of only 7.7°C for Silvoarable points.

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Table 38. Mean of diurnal temperature range values for MF/AC classes. PC – permanent crops, N – number of points, Min – minimum, Max – maximum, Lower Q – lower quartile, Upper Q – upper quartile, Var – variance, StDev – standard deviation, CoVar – coefficient of variation.

Land Use	N	Mean	Median	Min	Max	Lower Q	Upper Q	Var	StDev	CoVar
Grazed arable crops	556	8.8	8.6	0.0	13.3	7.7	9.7	2.5	1.6	18.2
Grazed PC	304	8.7	8.6	0.0	13.3	7.6	9.5	2.8	1.7	19.2
Home gardens	1220	8.8	8.7	0.0	13.5	7.7	9.7	2.5	1.6	17.9
Intercropped PC	81	8.6	8.4	5.6	13.3	7.5	9.3	2.3	1.5	17.6
Silvoarable	57	8.6	8.5	4.2	12.6	7.7	9.5	2.8	1.7	19.4
Silvopastoral	7822	8.7	8.6	0.0	13.5	7.6	9.7	2.7	1.6	18.7

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8 Climate change in Europe and its effects on MF/AF systems

8.1 A review of climate change

8.1.1 Overview

Observed and projected changes in European climate and climate-related impacts have been systematically assessed in several collaborative reports during the last two decades. These include those published by the Intergovernmental Panel on Climate Change (IPCC), specifically the Fifth (AR5; IPCC, 2014) and Sixth Assessment Reports (AR6; IPCC, 2021) and the Special Report on Extremes (SREX; IPCC, 2012). The IPCC Assessment Reports in particular constitute an extensive analysis of observational datasets and the latest generation of global climate models (GCMs).

8.1.2 Climate change information: current state of play

8.1.2.1 Climate modelling state-of-the-art

Projections published as part of the IPCC Assessment Reports have been typically generated using an ‘ensemble’ of simulations from a suite of global climate models developed at leading climate research institutes around the world. The intercomparison, assessment and evaluation of such models is coordinated by the Coupled Model Intercomparison Project (CMIP), the sixth phase of which, termed CMIP6, forms the basis of the AR6 projections. While the global climate models used in CMIP6 have the advantage of global coverage, their limited spatial resolution (around 1°) is insufficient for the realistic representation of small-scale processes and meteorological phenomena that are particularly important for analysis of regional-scale climate change. Regional Climate Models (RCMs) provide an opportunity to conduct higher-resolution experiments (up to 0.11°) over limited spatial domains in order to better resolve small-scale processes. Since the publication of AR5 in 2013, a wealth of subsequent work seeking to interpret and apply European climate scenarios has used high-resolution model simulation collated by the Coordinated Downscaling Experiment (CORDEX; Gutowski et al., 2016). Experiments using multiple RCMs driven by output from multiple GCMs have been conducted across both pan-European (EURO-CORDEX) and Mediterranean (MED-CORDEX) domains (Jacob et al., 2014; Ruti et al., 2016; Kjellström et al., 2018; Vautard et al., 2020; Coppola et al., 2021a).

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8.1.2.2 Defining climate change scenarios

The IPCC AR6 uses a set of scenarios to illustrate the range of anthropogenic drivers of climate change that may develop in the future. The latest set of scenarios are based on Shared Socioeconomic Pathways (SSPs), which build on the emissions-only Representative Concentration Pathways (RCPs) used in AR5. The SSPs start in 2015 and describe scenarios according to a range of greenhouse gas concentrations: very high (SSP5-8.5), high (SSP3-7.0) intermediate (SSP2-4.5), low (SSP1-2.6) and very low (SSP1-1.9).

In addition to the SSPs, AR6 also describes and quantifies changes according to Global Warming Levels (i.e. 1.5°C or 2°C above the 1850-1900 period). The Global Warming Levels are independent of the timing when the warming is reached and the emissions scenario that led to it. The SSPs and Global Warming Levels are illustrated in Figure 54.

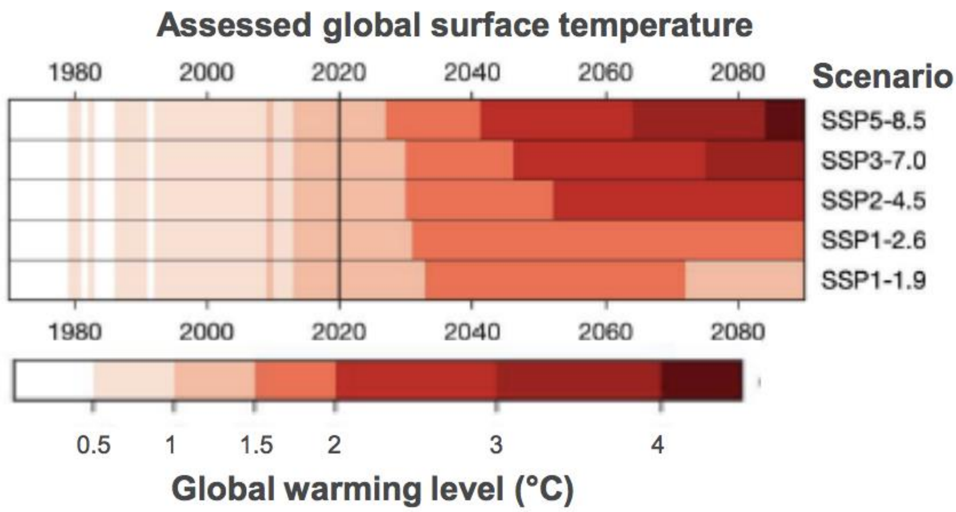

Figure 54. Observed and projected global surface temperature changes shown as global warming levels relative to 1850-1900 (source: IPCC Regional Fact Sheet introduction; IPCC, 2021).

8.1.3 Summarising observed and projected climate information

8.1.3.1 European climatological characteristics

The climate of the majority of Europe can generally be described as temperate, with distinct maritime and continental characteristics in the west and east respectively. Western Europe is strongly influenced by the Gulf Stream, which ensures far milder conditions in comparison to other regions of similar latitude. Variability on daily to seasonal timescales is dominated by westerly climatic features moving towards Europe from the Atlantic. Climate variations on longer timescales are driven to a greater extent by natural modes of variability in the climate system, including the North Atlantic Oscillation (NAO) and lower-frequency modes such as the El Nino Southern Oscillation (ENSO).

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8.1.3.2 Regionalising European climate information

Pan-European synthesis of observation- and model-derived climate change information is often split into predefined reference regions. Those used in the different assessment reports of the IPCC are the most commonly applied, and defined to reflect regions of broadly homogenous climatic and oceanic characteristics. In Europe, these characteristics range from sub-arctic to oceanic-continental to Mediterranean. The original 23 rectangular reference regions proposed by Giorgi and Francisco (2000) were adopted by the third (AR3; Giorgi et al., 2001) and fourth (AR4; Christensen et al., 2007) IPCC Assessment Reports. For the Fifth Assessment Report (AR5; van Oldenborgh et al., 2013), a modified set of 33 regions was used with the intention to better represent subcontinental-scale domains of climatic coherency. The availability of a greater number of global climate model products, coupled with the provision of more simulations at finer spatial resolution, led to efforts to further refine the existing reference regions (subsequently referred to as IPCC WGI reference regions, version 4; Iturbide et al. 2020). For Europe, the three core reference regions used to define Northern Europe (NEU), Central Europe (CEU; subsequently renamed Western and Central Europe, WCE) and Mediterranean Europe (MED) since AR3 were unchanged. However, the Iturbide et al. (2020) modifications have introduced a fourth region, Eastern Europe (EEU), to represent the continental climate west of the Urals mountains (Figure 55).

The IPCC Atlas (Gutiérrez et al., 2021), published as part of the AR6, provides regional scale synopses of historical and future climate changes, which are summarised in the remainder of this section. An important conclusion made by IPCC AR6 is that it is "virtually certain" that Europe will continue to become warmer, irrespective of the climate change scenario (Ranasinghe et al., 2021).

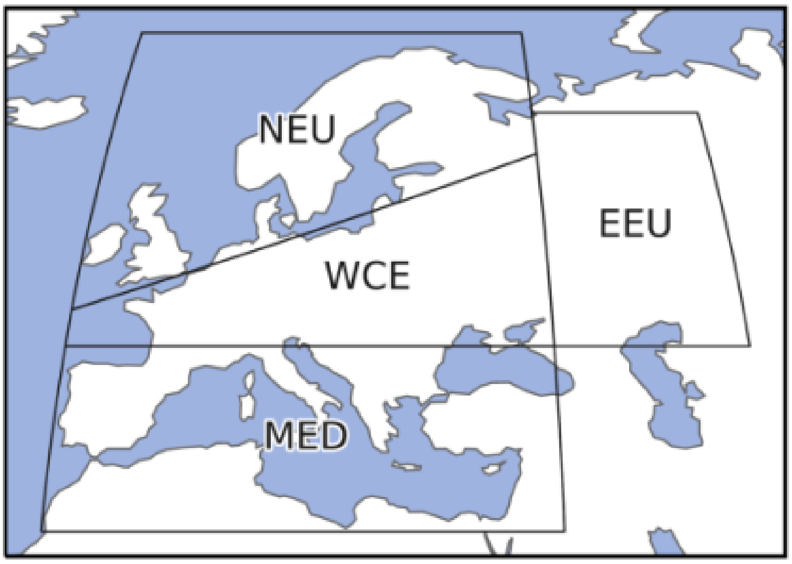

Figure 55. IPCC Climate Reference Regions for Europe (IPCC, 2021).

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8.1.3.3 Regionalised changes in climate impacts

The key changes in climate impacts associated with historical and future climate change can be broken down by European sub-regions.

Northern Europe (NEU) is dominated by maritime climate and exposure to Atlantic storms, and characterised by subsequently high levels of humidity and relatively mild winters (Gutiérrez et al., 2021). In general, the observed increase in pluvial flooding in recent decades can be attributed to anthropogenic activity, and further increases in both pluvial flooding and severe windstorms are expected to result from global warming levels of 2°C and above. By contrast, a decrease in fluvial (i.e. river) flooding is projected under the same scenario (IPCC, 2021; Table 39).

Western & Central Europe (WCE) is characterised by a distinct seasonal difference between summer and winter, with climate becoming increasingly continental in nature further eastwards (Gutiérrez et al., 2021). Among the key climate impacts observed during recent decades are an increase in the frequency and magnitude of river floods. The likelihood of both river and pluvial flooding is expected to increase during the 21st century, alongside an increase of hydrological and agricultural-ecological drought (IPCC, 2021; Table 39).

Eastern Europe (EEU) climate is characterised as continental with strong differences between annual maximum and minimum temperatures. It is important to note that any European observational datasets (e.g. E-OBS) and regional projections (e.g. EURO-CORDEX) do not sufficiently cover the full extent of this region (Gutiérrez et al., 2021), and so the climate information is broadly based on (and therefore limited by) the output of lower-resolution GCMs. Among the key projected changes in climate impacts are an increase in pluvial flooding and fire weather, alongside a decrease in river flooding (IPCC, 2021; Table 39).

Mediterranean Europe (MED) has been identified as one of the world's most vulnerable to climate change (Doblas-Reyes et al., 2021). The region's climate is characterised by hot, dry summers (including extreme summer temperatures) and by mild winters. The Mediterranean Sea is a source of evaporation that plays an important role in the hydrological cycle of the wider region (Doblas-Reyes et al., 2021). The Mediterranean climate is also influenced by strong feedbacks between the land and the atmosphere (Seneviratne et al., 2006), which can in turn lead to heatwaves and episodes of drought across southern and other parts of continental Europe (Zampieri et al., 2009). Current model simulations project a future warming of between 3.5°C and 8.75°C by the end of the 21st century and a reduction in precipitation across all seasons (Doblas-Reyes et al., 2021). The IPCC AR6 reported observed increases in both hydrological and agricultural-ecological drought during recent decades, and projected further changes in combinations of climate impact-drivers (e.g. extreme temperatures, drought conditions, fire weather) by the middle of the 21st century (IPCC, 2021; Table 39).

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Table 39. Summary of observed and projected changes in key climate impacts within the different European sub-regions (adapted from Europe Regional fact sheet; IPCC, 2021).

Sub-region	Changes	Confidence
Northern Europe	**Observed** increase in pluvial flooding attributed to human influence	High
	Projected increase in pluvial flooding at global warming of 2°C and above.	High
	Projected decrease in river flooding at global warming of 2°C and above.	Medium
	Projected increase in severe wind storms at global warming of 2°C and above	Medium
Western & Central Europe	**Projected** increase in pluvial flooding at global warming of 2°C and above.	High
	Observed increasing trend in river flooding.	High
	Projected increase in river flooding at 2°C and above of global warming.	High
	Projected increases in hydrological, agricultural and ecological droughts at mid-century warming levels of 2°C or above, regardless of the greenhouse gas emissions scenario.	Medium
Eastern Europe	**Projected** increase in pluvial flooding at global warming of 2°C and above.	High
	Projected decrease in river flooding at global warming of 2°C and above.	Medium
	Projected increase in fire weather at global warming of 2°C and above.	Medium
Mediterranean	**Observed** increase in hydrological and agricultural and ecological droughts.	Medium
	Projected increase in aridity and fire weather conditions at global warming of 2°C and above (high confidence).	High
	Projected combination of climatic impact-driver changes (warming, temperature extremes, increase in droughts and aridity, precipitation decrease, increase in fire weather, mean and extreme sea levels, snow cover decrease, and wind speed decrease) by mid-century and at global warming of at least 2°C and above.	High

8.1.4 Changes in agriculture-relevant climate impact-drivers

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 (IPCC, 2021). Throughout this section, figures generated using the IPCC Interactive Atlas are used to supplement findings presented in the IPCC AR6 and supporting work.

8.1.4.1 Mean temperature and precipitation

The warming trend of *mean air temperature* detected in AR5 has been confirmed in many subsequent studies and can very likely be attributed to anthropogenic climate change (Eyring et al., 2021). Irrespective of the emissions scenario, it is virtually certain that the current European warming trend will continue (Gutiérrez et al., 2021). There is a strong degree of consistency in the patterns of trends in observations and those derived from climate model simulations (Ranasinghe et al., 2021). Trends in temperature are very likely to continue under all future warming scenarios (Gutiérrez et al., 2021; Figure 57a,c,e).

In general, changes in *mean precipitation* respond to a north-south distinction in European precipitation climatology, with northern Europe generally becoming wetter and Southern Europe drier (Figure 57b), particularly during winter (Fischer and Knutti, 2016; Knutson and Zeng, 2018). The north-south pattern is evident in both global and regional climate model simulations Jacob et al., 2014; Rajczak and Schär, 2017; Lionello and Scarascia, 2018; Coppola et al., 2021), although there, uncertainty stems from disagreement about the position and range of the region in between. The latest CMIP6 ensemble, alongside EURO-CORDEX and MED-CORDEX experiment, projects further precipitation increases in northern Europe (particularly during winter; Figure 56d) and decreases in the Mediterranean (particularly during summer; Figure 57f) in all but the most optimistic climate change scenarios (Prein et al., 2016; Ranasinghe et al., 2021).

8.1.4.2 Hot and cold extremes

There is high confidence that the increase in extreme heat observed during recent decades can be attributed to anthropogenic activities (Gutiérrez et al., 2021). It is highly likely that the likelihood of high temperature extremes will increase during the remainder of the 21st century, and that this trend will be particularly pronounced in southern Europe. Spatial patterns in extreme temperature changes are expected to respond in a similar manner to mean temperature (Figure 57a,c). It is expected that critical societal thresholds (e.g. those relevant for health and agriculture) will be exceeded with growing frequency. The frequency of European heatwaves has increased in recent decades and is very likely a consequence of anthropogenic activity (Ranasinghe et al., 2021). It is very likely that this increase will continue during the 21st century regardless of the warming scenario Seneviratne et al., 2021). Heat stress associated with high temperature and humidity levels is also projected to increase.

The number of *cold spells* and *frost days* will continue to decrease during the remainder of the 21st century (Gutiérrez et al., 2021) (Figure 57d). Observational evidence suggests that winter cold spells are becoming less likely (Brunner et al., 2018), a trend that is expected to continue throughout the 21st century (Seneviratne et al., 2021). Both global and regional model simulations project a decrease in the frequency of *frost days* irrespective of the emission scenario (Lindner et al., 2014; Coppola et al., 2021; Ranasinghe et al., 2021; Figure 57d).

8.1.4.3 Wet and dry extremes

Trends in the frequency of *heavy precipitation* are evident across Europe, particularly in northern Europe and in Alpine regions, and there is growing evidence of an anthropogenic fingerprint in such trends (Gutiérrez et al., 2021; Figure 58a,b). High-resolution model simulations, including both RCMs and, to a greater extent, convection-permitting models (CPMs) are better equipped to resolve small-scale processes associated with extreme precipitation. Analysis of the EURO-CORDEX ensemble showed a projected increase in extreme precipitation events across continental Europe, with the most intense increases evident over the Western and Central Europe and Mediterranean regions (Coppola et al., 2021).

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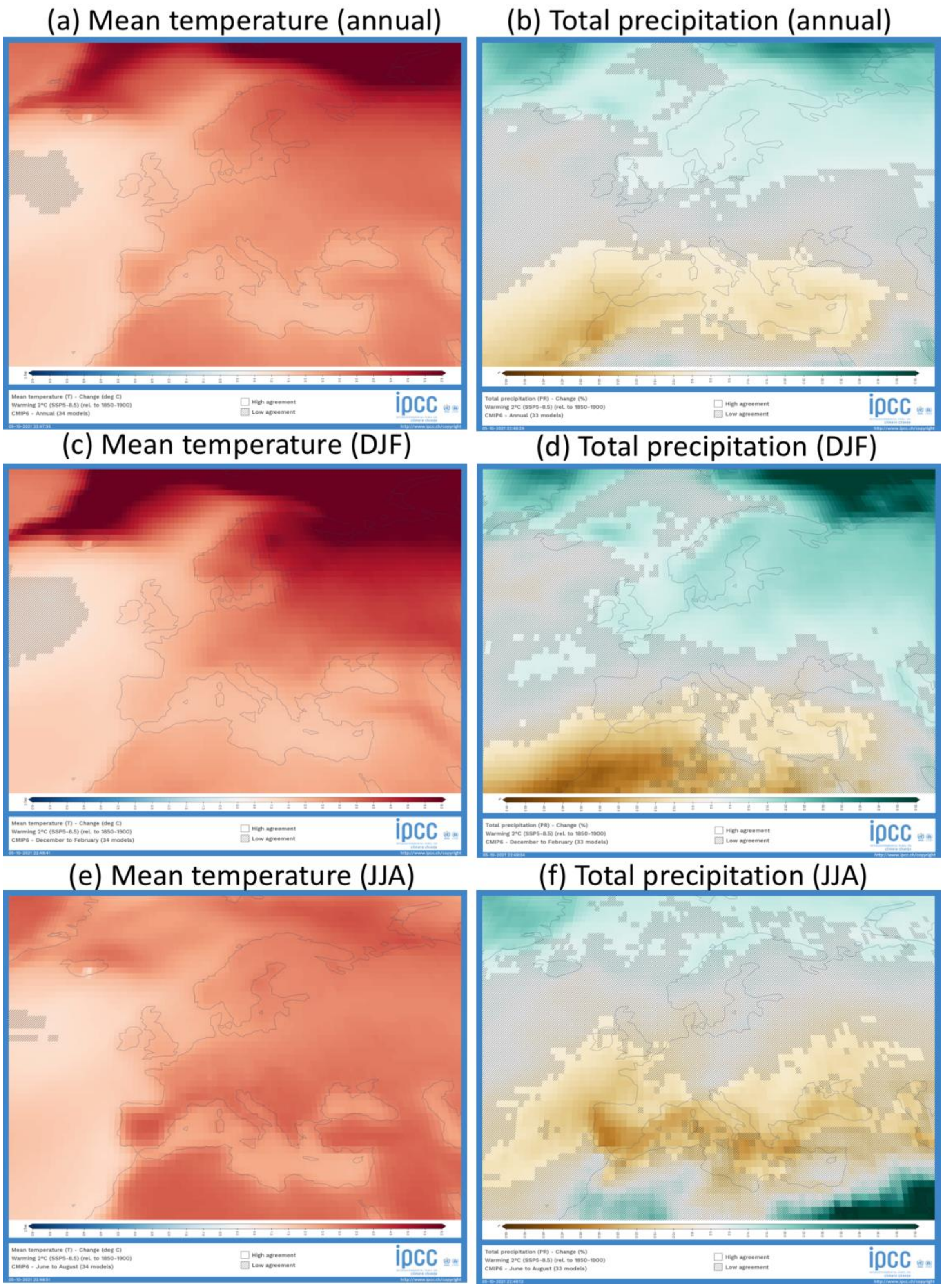

*Figure 56. European climate projections under the 2°C global warming level for (a) mean annual temperature, (b) total annual precipitation, (c) mean December-February (DJF) temperature, (d) total DJF precipitation, (e) mean June-August (JJA) temperature, and (f) total JJA precipitation. All figures generated by the IPCC Interactive Atlas (**https://interactive-atlas.ipcc.ch/**).*

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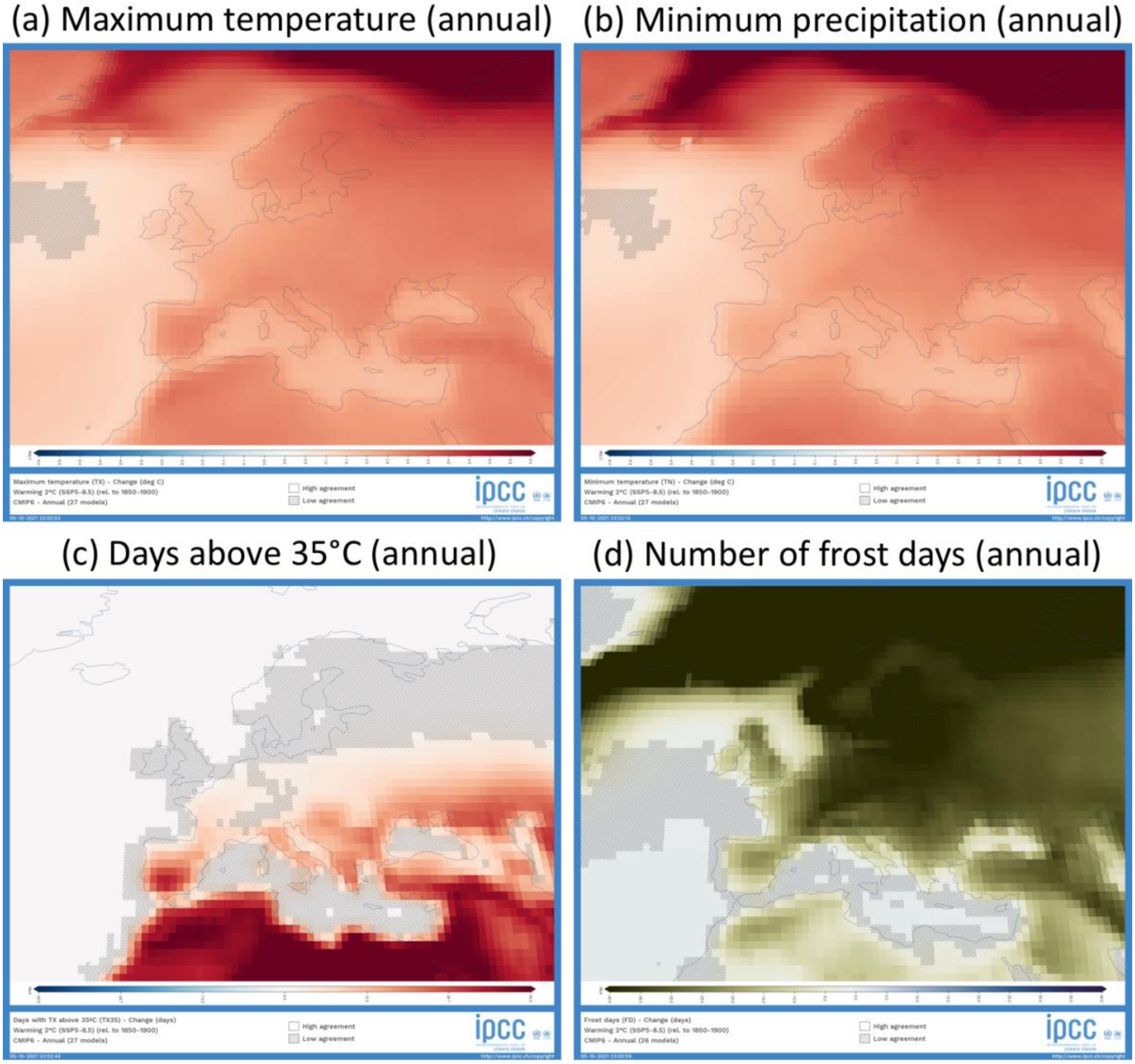

Figure 57. European annual climate projections under the 2°C global warming level for (a) maximum annual temperature, (b) minimum annual temperature, (c) number of days with temperature greater than 35°C, and (d) number of frost days. All figures generated by the IPCC Interactive Atlas (https://interactive-atlas.ipcc.ch/).

Episodes of *hydrological drought* (i.e. a period of particularly low precipitation) have become more frequent across most of central and western Europe in recent decades. In much of northern and southern Europe, there is evidence of a decreasing trend (Gutiérrez et al., 2021; Figure 58c). Streamflow deficits (i.e. lower-than-usual flows) are expected to become more intense and longer-lasting in both Mediterranean and western Europe; Forzieri et al. (2016) estimated that 100-year events could become 2- to 5-year events by 2080. Higher precipitation in other parts of Europe means that streamflow deficits are likely to become smaller, despite the effects of increased evapotranspiration (Forzieri et al. 2014; Figure 58d).

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The IPCC AR6 defines *agricultural and ecological drought* as "a period with abnormal soil moisture deficit, which results from combined shortage of precipitation and excess evapotranspiration, and during the growing season impinges on crop production or ecosystem function in general" (IPCC, 2021). With respect to such episodes, IPCC AR6 projects increases in both the Mediterranean and Western & Central Europe regions by the mid-21st century (with medium and high confidence respectively) (Seneviratne et al., 2021). These projections are supported by numerous studies conducted at the local scale in recent years, many of which are noted by Ranasinghe et al (2021). Southern Europe, in particular, is expected to become associated with more severe agricultural and ecological droughts during the 21st century. Guerreiro et al. (2018) identified areas of southern Europe where droughts that are currently considered severe in the context of the historical record could increase by a factor of up to 14. Drought episodes that currently occur once every 10 years are projected to become up to five times more likely (Mora et al., 2018; Ruosteenoja et al., 2018). The situation is less severe in other parts of Europe; in Northern Europe, winter drought events are expected to decrease in both frequency and intensity (Spinoni et al., 2018).

8.1.5 Summary

A summary of the most important projected changes for European climate according to IPCC AR6 (IPCC, 2021) is as follows:

- European temperatures will rise at a rate exceeding that of global mean temperature.
- The increase in the frequency and magnitude of heatwaves in recent decades is projected to continue.
- The frequency of cold spells and frost days is projected to decrease.
- Current trends in European mean and extreme temperatures would not be possible without the anthropogenic influence on the climate system.
- Decreases in rainfall are projected in the Mediterranean region, particularly during summer. In other regions of Europe, extreme rainfall and pluvial flooding are projected to increase.
- Shorelines and sandy coasts will retreat throughout the 21st century as a result of relative sea level rise.
- The observed decrease in glacial, permafrost and snow cover extent is projected to continue.

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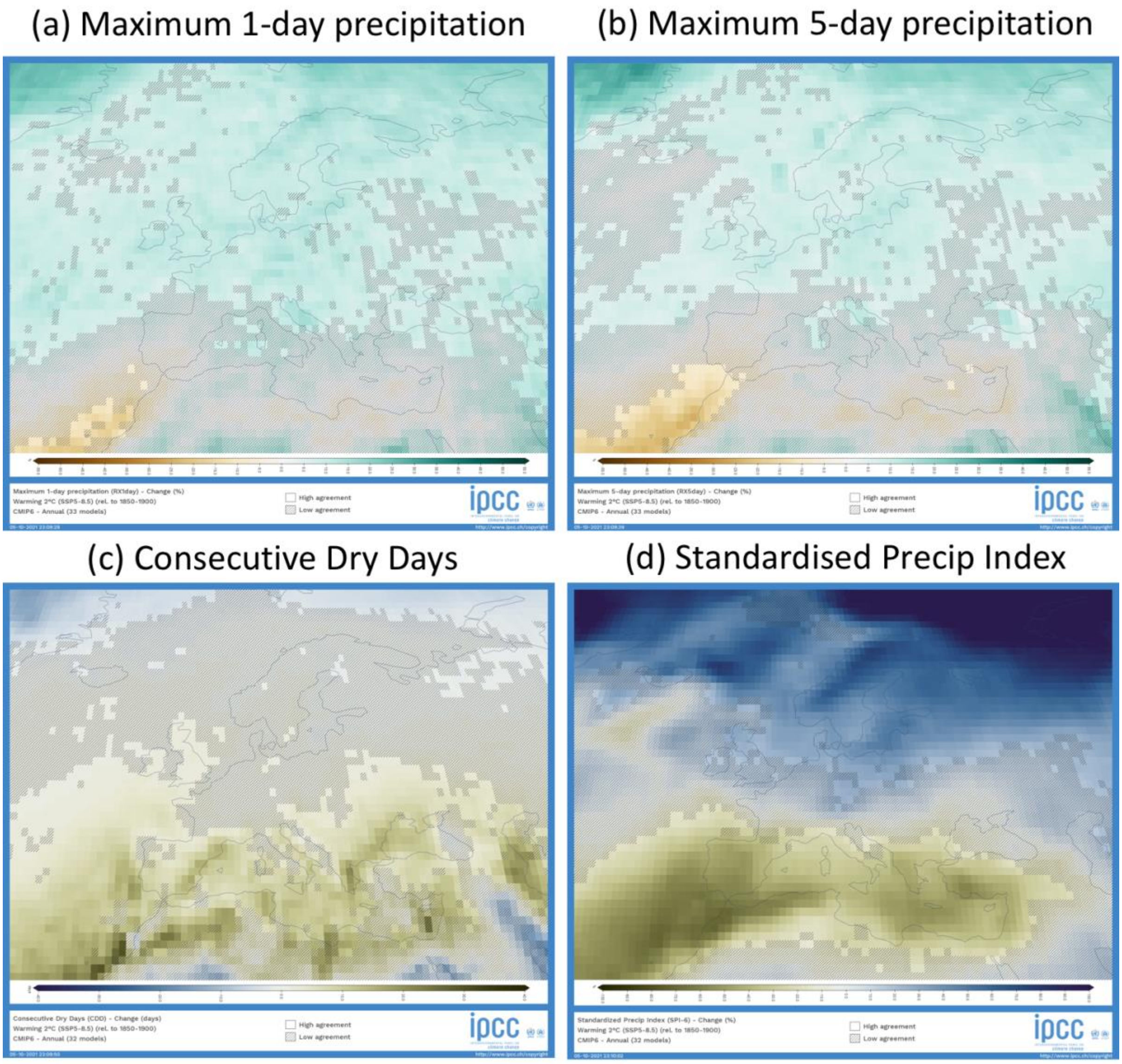

Figure 58. European annual climate projections under the 2°C global warming level for (a) maximum 1-day precipitation (RX1day), (b) maximum 5-day precipitation (RX5day, (c) Consecutive Dry Days (CDDs), and (d) Standardised Precipitation Index (SPI-6). All figures generated by the IPCC Interactive Atlas (https://interactive-atlas.ipcc.ch/).

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8.2 Effects of climate change on MF/AF systems

In a recent briefing paper, Augére-Granier (2020) stated that agroforestry systems, being sustainable and multifunctional, provide many environmental benefits, and contribute also to climate change adaptation and mitigation. This publication is mainly based on the outcomes of the AGFORWARD project (Burgess et al., 2018), although the research carried out in this project focussed more on ecosystem services provided by AF, rather than their resilience to CC. Many researchers agree about the higher resilience of MF/AF systems as compared to other more intense agricultural systems (Mosquera-Losada et al., 2018; Lawson et al., 2019).

Tsonkova et al. (2012) reviewed the ecosystem services provided by silvoarable systems, in particular alley cropping in temperate regions. They identified benefits related with CC, such as increased carbon sequestration, improved soil fertility, enhanced biodiversity and increased overall productivity, although considering these systems on marginal lands. Other studies reporting on resilience of MF/AF systems (including agroecological farming) include Pimbert (2015) and Wilson and Lovell (2016).

Reviewing the effect of climate change (CC) on MF/AF systems is very complex as different regions in Europe are affected in different ways as described in the previous Section. The question is: how will agricultural activities in Europe be affected by CC, and particularly MF/AF systems? But more interesting is to know whether MF/AF systems are less affected by CC then their more intense/mono agricultural counterparts. This relates with resilience of the different systems. Given the spatial variations of CC impacts in Europe and the particularly large impact in the Mediterranean region, in the following some general reflections are made.

Figure 59 shows the most relevant CC impacts on agriculture in the Mediterranean, most notably temperature increase, reduction of rainfall and increase of drought frequency. These provoke a reduction of soil water availability for plants as a consequence of higher evapotranspiration and reduced rainfall and an increase of wildfire risk, as well as a reduction of soil carbon storage and soil quality. Figure 59 compares MF/AF systems with more simpler land use/land cover types: i) Monocropping versus Mixed livestock farming, ii) Monocropping vs. AF and iii) Forestry vs. AF, indicating how the most important elements of resilience would be affected, either positively (+) or negatively (-). Also, depending on diverse factors, both could be possible. Furthermore, there are still unknown consequences, which still need to be investigated and are actually subject of research carried out in AGROMIX, particularly in WP3. There are effects which are common to all three comparisons, included in the blue rectangle of Figure 55, being mostly positive. Positive environmental effects include the increase of biodiversity and of landscape diversity. Economic consequences are diversification of production and increase of employment, and social effects include healthier food (probably not in all cases or stays unchanged), fixing population in rural areas and maintaining cultural heritage.

Comparing Forests with Agroforestry may imply negative effects such as an increase of soil erosion and a reduction of soil carbon storage. Generally, it implies important positive effects, such as a reduction of wildfire risks which constitutes a big problem in forests of Mediterranean areas. Forests have generally low production in this climate, so that agroforestry uses imply greater economic income.

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When comparing Monocropping with Mixed livestock farming and Agroforestry, a positive effect can be expected related with an increase in soil fertility, soil carbon stock and a reduction of soil erosion. Furthermore, the conversion from Monocropping to AF may provoke also negative effects, such as a reduction of crop production or excessive water consumption by trees with reduced water availability for temporary crops.

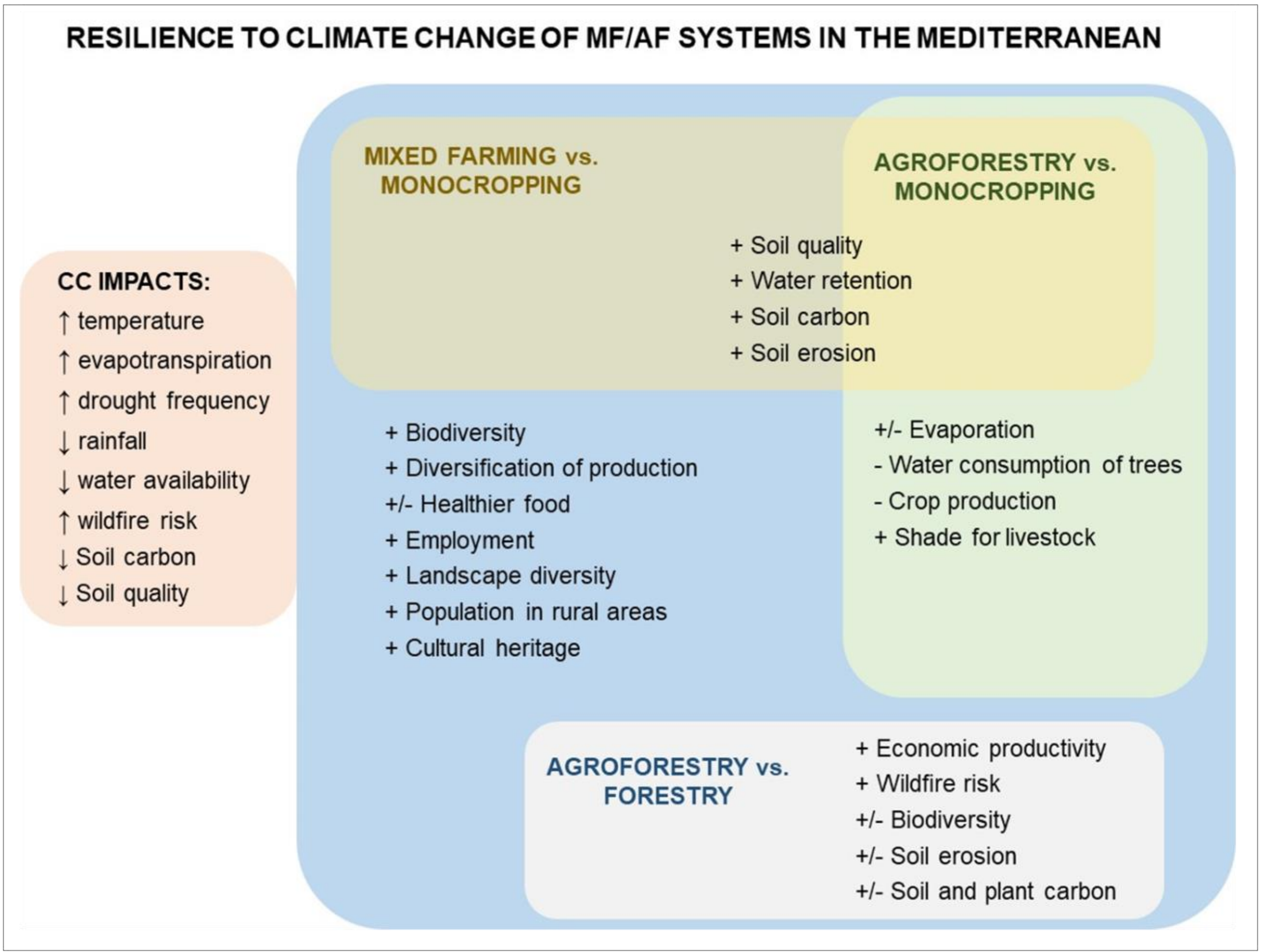

Figure 59. Resilience to climate change impacts of MF/AF systems, as compared to simple systems (monocropping, forestry), in the Mediterranean. + and - indicates if the effect is beneficial or adverse and does not necessarily mean an increase or decrease of the variable. +/- the effect may either be positive or negative, or still needs to be investigated.

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9 Geographical data of MF/AF systems in Europe

With the purpose of sharing spatial and geographical information within the AGROMIX consortium and to allow the adequate dissemination of this information and the project results, all the geographical data, spatial information and maps of the AGROMIX project are being integrated into geographical databases covering the different aspects that incorporate the physical and natural geoinformation as well as socio-economic data. This database will be used for the research on upscaling that will be carried out in work package 3, task 3.

Characteristics of the Geodatabases containing the spatial information and maps:

INSPIRE (Infrastructure for spatial information in Europe, https://inspire.ec.europa.eu/) technical guidance documents and recommendations have been followed when necessary.

The main technical characteristics of the database are listed here:

- Geodatabase format: ESRI File Geodatabase (File GDB) including both raster and vector data typologies.
- Geodetic datum and coordinate reference system: European Terrestrial Reference System 1989 (ETRS89). Plane coordinates using the ETRS89 Transverse Mercator coordinate reference system.

The data availability in the geodatabases is listed below:

Reference and multipurpose data and spatial information:

- EuroGlobalMap and EuroRegionalMap: 1:1000000 scale topographic dataset covering multi-themed topographic open data of Europe.
- NUTS 2021: The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU and the U. Classification valid from 1 January 2021 and lists 92 regions at NUTS 1, 242 regions at NUTS 2 and 1166 regions at NUTS 3 level.
- EUROSTAT Agri-environmental indicators (AEIs). Set of 28 agri-environmental indicators for the European Union (EU) intended to monitor the integration of environmental concerns into the Common agricultural policy (CAP).

Land use and land cover data:

- LUCAS databases (Land Use and Coverage Area frame Survey): d'Andrimont, R., Yordanov, M., Martinez-Sanchez, L., Eiselt, B., Palmieri, A., Dominici, P., Gallego, J., Reuter, H.I., Joebges, C., Lemoine, G. and van der Velde, M., 2020. Harmonised LUCAS in-situ land cover and use database for field surveys from 2006 to 2018 in the European Union.

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- CORINE Land Cover: 1990, 2000, 2006, 2012 and 2018 information of the CORINE land cover survey and interannual changes.
- COPERNICUS High resolution Layers: Pan-European High Resolution Layers (HRL) provide information on specific land cover characteristics, and are complementary to land cover / land use mapping such as in the CORINE land cover (CLC) datasets. Information is provided about imperviousness, forest, grassland, water and wetness and small woody features.
- European Settlement Maps mapping human settlements in Europe based on SPOT5 and SPOT6 satellite imagery
- Global land cover - 250m: The project was carried out to provide accurate baseline landcover information to the International Conventions on Climate Change, the Convention to Combat Desertification, the Ramsar Convention and the Kyoto Protocol.
- Pan-European Land Use and Land Cover Monitoring (PELCOM): 1-km pan-European land cover database from NOAA-AVHRR satellite data and ancillary data.
- Pan-European land cover map of 2015 based on Landsat and LUCAS data. PANGAEA. From Pflugmacher, D. et al. (2019): Mapping pan-European land cover using Landsat spectral-temporal metrics and the European LUCAS survey. Remote Sensing of Environment, 221, 583-595.

Soil data:

- European Soil Database v2 Raster Library 1kmx1km. This database (2006) is a set of raster data sets that have been derived from the European soil Database v2, for most attributes. The values for the attributes are categorized (non-continuous). These rasters are an interpretation of the data that are contained in the ESDB v2.0
- European Soil Database v2.0 (vector and attribute data). This database (2004) is the only harmonized soil database for Europe, extending also to Eurasia. It contains a soil geographical database SGDBE (polygons) to which a number of essential soil attributes are attached, and an associate database PTRDB, with attributes values that were derived through pedotransfer rules. Also, part of the database is the Soil Profile Analytical Database, that contains measured and estimated soil profiles for Europe.
- Maps of Soil Chemical properties at European scale, based on LUCAS 2009/2012 topsoil data. 500 m resolution data about pH (measured in H_2O) pH (n $CaCl_2$ 0.01 M solution), Cation Exchange Capacity (CEC), Calcium carbonates ($CaCO_3$), C:N ratio, Nitrogen (N), Phosphorus (P), Potassium (K) based on LUCAS 2009 topsoil samples.
- Topsoil physical properties for Europe (based on LUCAS topsoil data). 500 m resolution data about clay content, silt content, sand content, coarse fragments, bulk density, USDA soil textural classes and available water capacity based on LUCAS 2009 topsoil samples.
- European Soil Database Derived data, 1000 m resolution. A number of layers for soil properties based on data from the European Soil Database in combination with data from the Harmonized World Soil Database (HWSD) and Soil-Terrain Database (SOTER). The available layers include: Total available

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water content, Depth available to roots, Clay content, Silt content, Sand content, Organic carbon, Bulk Density, Coarse fragments.
- Google Earth Files (with ".kmz" extension) that correspond to 73 attribute maps derived from the European Soil Database v2 (ESDB v2) for EU27 countries. The list of attributes is listed in https://esdac.jrc.ec.europa.eu/content/google-earth-files.

Climate data:

- Agroclimatic indicators from 1951 to 2099 derived from climate projections. 0.5° x 0.5° lat-lon agroclimatic indicators used to characterise plant-climate interactions for global agriculture.
- COPERNICUS climate change service E-OBS data. Ensemble mean dataset is available on a 0.1° and 0.25° regular grid for the elements daily mean temperature TG, daily minimum temperature TN, daily maximum temperature TX, daily precipitation sum RR, daily averaged sea level pressure PP, daily averaged relative humidity HU, daily mean wind speed FG and daily mean global radiation QQ. They cover the area: 25N-71.5N x 25W-45E. The data files are in NetCDF-4 format.

Topographic data:

- EU-DEM: Digital surface model of EEA members and cooperating countries representing the first surface as illuminated by the sensors. It is a hybrid product based on SRTM and ASTER GDEM data fused by a weighted averaging approach.
- European Mountain Areas: The delineation of European mountain areas was carried out by using digital elevation models, considering different criteria combination of thresholds of altitude, climate, and topography variables.
- Global Landform classification: Represent global landform classification according to 1) Meybeck et al., presenting relief classes, which are calculated based on the relief roughness, and 2) Iwahashi and Pike, presenting relief classes which are classified using an unsupervised nested-means algorithms and a three-part geometric signature.
- Meybeck, M., P. Green and C. J. Vorosmarty (2001), A New Typology for Mountains and Other Relief Classes: An Application to Global Continental Water Resources and Population Distribution, Mount. Res. Dev., 21, 34 - 45.
- Iwahashi, J. and R. J. Pike (2007). "Automated classifications of topography from DEMs by an unsupervised nested-means algorithm and a three-part geometric signature." Geomorphology 86(3-4): 409-440.

Biogeography, environment data:

- Biogeographical regions: The biogeographical regions dataset contains the official delineations used in the Habitats Directive (92/43/EEC) and for the EMERALD Network set up under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention).

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- The Environmental Stratification of Europe: Metzger, Marc J. (2018). The Environmental Stratification of Europe, [dataset]. University of Edinburgh. https://doi.org/10.7488/ds/2356. 1km spatial resolution. The dataset distinguishes 84 strata that are relatively homogeneous in environmental conditions and can be aggregated into 13 environmental zones (EnZ) all over Europe.

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10 Summary

A **classification of mixed farming and agroforestry systems** in Europe was proposed, recognizing seven classes:

- Silvopastoral
- Agrosilvopastoral
- Silvoarable
- Grazed Permanent crops (PC)
- Intercropped PC
- Grazed arable (temporary) crops
- Home gardens.

Agricultural areas that were not included in the above classes, but with **woody linear features** (WLF), were considered separately, distinguishing three classes:

- Arable land with WLF
- Grazed grasslands with WLF
- Permanent crops with WLF

These MF/AF classes were used in an analysis carried out using land use/land cover data provided by Eurostat (LUCAS surveys) and for this reason, the only mixed farming system considered here was grazed arable crops. Other MF systems could not be identified with the LUCAS database and were hence not considered in the geographical analysis of MF/AF systems. This is a serious limitation and consequently other MF systems which include combinations of livestock rearing with temporary or permanent crops were ignored. MF enterprises represent approximately 10% of all farms in the European Union, a figure that justifies a more in-depth analysis regarding the spatial extend and distribution of MF in Europe and its representation in different biogeographical regions.

A further **limitation of our analysis** is due to the existence of AF systems which cannot be fully recognized using LUCAS data. Examples are forest farming (e.g. forestry combined with the acquisition of wild meat, honey, etc.) or silvopastoral systems where grazing intensity is low or animals are not permanently in the area, so that this activity cannot be identified by the surveyor in the field. Furthermore, reindeer husbandry, of great economic and cultural importance in northern Scandinavia, is probably not taken sufficiently into account with our analysis.

The **analysis of land use and land cover data** was carried out using the homogenized data set produced by d'Andrimont et al. (2020) of survey years 2009, 2012, 2015 and 2018. The most recent dataset was used to analyse the extent and spatial distribution of MF/AF systems in Europe, as well as areas with WLF. The whole data set from 2009 until 2018 was applied in the analysis of temporal changes of MF/AF systems.

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The present **extent of MF/AF systems in Europe** can be summarized as follows:
The estimated total surface area occupied by mixed farming and agroforestry in the EU is 132,955 km^2, which represents 7.7% of utilized agricultural area (UAA). Silvopastoral land use is the dominant MF/AF system, occupying nearly 78% of the total, followed by Home gardens with about 12% (16,173 km^2). Grazed arable crops present only 5.5% (7,358 km^2) of the total MF/AF area. Agroforestry systems with permanent crops, either grazed (3.0%) or intercropped (0.8%) are relatively scarce. Silvoarable and agrosilvopastoral systems are poorly represented, with 0.6% and 0.2%, respectively.

Regarding the **spatial distribution of MF/AF farms in the EU**, Spain is the country with the largest surface area (34,671 km^2), followed by Greece (16,934 km^2) and France (12,646 km^2). Also, Italy and Portugal have an important share of MF/AF systems. These five countries together represent approximately 67% of the total surface area occupied by MF/AF systems in EU-28. However, when expressing the surface area occupied by MF/AF systems as a percentage of UAA, Greece is the country with the highest proportion (37.2%). MF/AF systems occupy more than 20% of UAA in Cyprus and Portugal, and >12% in Sweden, Spain and Slovenia. At the other extreme are countries like Poland, Germany, Denmark, The Netherlands, United Kingdom and Ireland with ≤ 2.5% of their UAA occupied by MF/AF systems.

More detailed information about the **main characteristics of MF/AF systems**, and their distribution regarding member states and with respect to **biogeographical regions** is provided in Section 3.2.

Wooded linear features (WLF) were also investigated in this study using the most recent data of from 2015, considering managed and abandoned hedgerows, lines of heath or shrubs, single trees, avenue trees, conifer hedges, and groves/woodland margins which include riparian vegetation and buffer strips. The LUCAS survey only includes WLF of 1-3 m width. Abandoned hedgerows are the most abundant type, representing approximately 30% of all WLF points, followed by heath and shrubs (19%), avenue trees (18%) and managed hedgerows (17%).
Almost a quarter of all considered land uses with WLF are found in France. The United Kingdom shares also a large proportion of the total number of points (12.6%), followed by Spain and Germany, with 9.2 and 9.1%, respectively.
The most frequent land use type with WLF was arable crops, representing 59% of the total number of points, followed by grazed grasslands (28%). The least frequent land use type was permanent crops with WLF (13%). Given the abundance of wooded linear features in agricultural areas, they need to be taken into account as they constitute important elements which increase landscape diversity and biodiversity.

The most relevant research about the extent and distribution of agroforestry systems in Europe was carried out in the framework of the AGFORWARD project (Den Herder et al., 2015; 2017). These authors estimated the total surface area occupied by AF systems for EU-27 using data from LUCAS survey 2012 to be 154,000 km^2, equivalent to 3.6% of its territory. This value includes land uses equivalent to the AGROMIX classes silvopastoral, silvoarable, agrosilvopastoral and grazed and arable permanent crops. We considered also grazed shrubland as AF, which is the reason why our estimate is somewhat higher for that year (173,653 km^2). Furthermore, also home gardens were regarded AF, resulting in a total extent of agroforestry systems

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of approximately 191,000 km^2, representing 11% of utilized agricultural area (UAA) in the European Union for 2012. The figures presented by Mosquera-Losada et al. (2018), also based on the 2012 survey, included home gardens as well as shrublands without tree cover and presented similar data than ours. Likewise, Plieninger et al. (2015) studied AF systems, with a focus on wood pastures. All these studies applied different classifications, which is important to take into account when comparing the results.

Mixed farms are defined in AGROMIX as those where temporary crops are cultivated in combination with livestock rearing. LUCAS data allowed an estimation of the surface area of grazed arable crops (temporary crops + grazing livestock), but does not include other mixed systems, for example where cropland is combined with stabled domestic animals. The estimated surface area of grazed arable crops using LUCAS data resulted in 7358 km^2 which represents only 0.43% of UAA.

Based on Eurostat data, the extent and spatial distribution of MF in EU-28 was analysed. The total extent of MF amounts to 198,927 km^2, corresponding to 11.2% of UAA. These values are much higher than the surface area presented above for grazed arable crops, based on LUCAS data. Regarding the share of MF for individual EU countries, a large spatial variation was detected, with highest values in Czechia, Slovenia and Poland (>20%). Values below 5% of UAA were found in Greece, Italy, Cyprus, Netherland, Bulgaria and Ireland. Data analysed using a higher resolution (NUTS-2), spatial variation is even more pronounced.

Furthermore, changes of MF between 2005 and 2013 were analysed, demonstrating a marked decrease, particularly of the farm type various crops combined with livestock. Also, temporal changes varied strongly between individual member states.

Recent changes of MF/AF systems were investigated using the 4 LUCAS surveys for the period 2009 – 2018. The total area occupied by MF/AF systems did change very little between 2009 and 2018, with 102,449 and 100,555 km^2, respectively. However, differences between land use classes were detected when analysing change from 2009 to 2018: i) Grazed as well as intercropped permanent crops decreased by 41.5% and 32.9%, respectively; ii) Silvopastoral land uses maintained stable; iii) the surface area occupied by home gardens increased by 19.7%. However, within this period remarkable variations were detected, with a strong increase of MF/AF extent between 2009 and 2012, followed by a decrease from 2012 onwards. These changes were particularly notable in silvopastoral systems and were mainly related with changes of grazing activity. Further research is necessary investigate the causes of these changes or whether they could be an artefact of the survey itself.

Regarding extent changes of agroforestry systems during the last decade in the European Union, to our knowledge, no research has been carried out about this subject so far. The surface area occupied by AF (including home gardens) was nearly stable between 2009 and 2018, with 102,449 and 100,555 km^2, respectively. Similarly, the extent of UAA in the European Union remained nearly unchanged between 2010 and 2019, with 1,801,370 and 1,791,450 km^2 (EUROSTAT). Spain, the country with the greatest extent of AF, also registered very little variation of UAA, with 24,190 and 24,434 km^2 for 2009 and 2020. There are, however, differences between AF classes when comparing years 2009 and 2018: i) Grazed as well as intercropped permanent crops decreased by 41.5% and 32.9%, respectively; ii) Silvopastoral land uses, by far the AF system with greatest extent, maintained stable; iii) the surface area occupied by home gardens

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increased by 19.7%. The decrease of silvoarable systems is in line with the decline reported by Eichhorn et al. (2006) for the second half of the 20th century. There were, however, changes between survey years, with a notable increase of MF/AF between 2009 and 2012, followed by a decrease from 2012 onwards. These changes were particularly remarkable in silvopastoral systems and were mainly produced by changes related with grazing activity. Further research is necessary to prove whether LUCAS point changes are related with land use changes or rather an artefact of the survey.

Physio-geographic characteristics of MF/AF systems in Europe

The spatial distribution of MF/AF data points was analysed regarding its relation with topography and climate, considered key natural factors in agricultural activities. This included a characterization of topographic and climatic conditions of MF/AF systems in the European Union.

Regarding **topography**, MF/AF land uses predominantly occur at lower elevations, at gentle slopes and very low curvatures. These overall trends obscure some differences between the various MF/AF land use types. Although most land uses indeed occur predominantly at low elevations, both silvopastoral and silvoarable land uses occur on higher elevations as well. Particularly silvopastoral land use is highly diverse, occurring over a wider range of elevations, slope steepnesses, slope aspects and curvatures than any of the other MF/AF land use types.

Furthermore, elevations and slope gradients of MF/AF systems are more frequent on steeper slopes than the complete European dataset, and on the contrary, are less frequent at very low elevations and very low slopes as compared with the EU as a whole. Finally, it is notable that Southern Europe exhibits a higher versatility of topographies for MF/AF land use. However, more research is necessary in order to define whether this is due to a higher versatility of MF/AF systems in Southern Europe, or due to a wider range of topographies in this area.

In relation with **climate characteristics** of MF/AF land uses, 5 variables were selected: annual precipitation, mean, maximum and minimum temperature and diurnal temperature range. When MF/AF classes were considered as a whole and grouped according to biogeographical regions, many significant differences were detected. On the contrary, grouping the data by MF/AF classes did not result in significant differences. The latter means that single MF/AF classes do not show distinct climate characteristics or we were not able to prove them. This is related with the fact that each class is distributed throughout Europe, although it may be more frequent in a particular biogeographical region. Furthermore, the distribution of sample sizes is uneven, with some land use classes having very few points.

Considering all MF/AF data points together and grouped according biogeographical regions, their climatic characteristics can be summarized as follow:

Mean annual precipitation of MF/AF systems is highest in the alpine biogeographical region, with approximately 1050 mm, followed by the Atlantic region (1000 mm), with the former showing higher variation. Steppic and Black Sea are the regions where MF/AF systems have the lowest precipitation, followed by Pannonian and Mediterranean, the latter being the region with the highest variation. Points located in the Boreal and the Atlantic region registered average annual precipitation of 717 and 846 mm, respectively, the former of less temporal variation.

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Regarding air temperature and the diurnal temperature range of MF/AF systems, the Continental and the Atlantic regions have similar mean daily temperature (9.6°C, 10.4°C), but Continental shows a higher diurnal temperature range. Lowest mean temperature (4.6°C) corresponds to points located in the Boreal region. Mean temperature was highest in the Mediterranean, followed by Black Sea with 14.5°C and 12.4°C, respectively.

Although our results offer a characterization of the main topographic and climatic conditions of MF/AF systems in the EU for different biogeographical regions, a more in-depth analysis is necessary to identify if these just reflect the characteristics of the corresponding region. For this it is necessary to compare MF/AF characteristics with the whole data set and, as well, with points corresponding to other land uses, such as more intensive or simpler agricultural and forest uses.

Climate change impacts on MF/AF systems

The most important projected changes for European climate according to the recent projections published by the IPCC panel are as follows:

- European temperatures will rise and the frequency and magnitude of heatwaves will increase.
- The frequency of cold spells and frost days are projected to decrease.
- Current trends in European mean and extreme temperatures would not be possible without the anthropogenic influence on the climate system.
- Decreases in rainfall are projected in the Mediterranean region, particularly during summer. In other regions of Europe, extreme rainfall and pluvial flooding are projected to increase.
- The observed decrease in glacial, permafrost and snow cover extent is projected to continue.
- In the Mediterranean region drought frequency is projected to increase.
- Shorelines and sandy coasts will retreat throughout the 21st century as a result of relative sea level rise.
- The observed decrease in glacial, permafrost and snow cover extent is projected to continue.

The most important impacts of CC on MF/AF systems were described using the Mediterranean region as an example. These systems offer advantages regarding their resilience to CC as compared to more intensive land uses (monocropping). Also, agroforestry systems when compared with forestry offer clear advantages, such as the reduction of wildfire risk and higher economic revenue. However, a more thorough review of the impact of climate change on MF/AF systems has to be carried out. On the other hand, there are still knowledge gaps which are subject of investigation in WP3 of the AGROMIX project.

The results produced in task 1.4 were integrated into a **data base** which also includes a whole set of **spatially distributed information**, such as topography, climate, soils, land use, land cover and tree density, which will be used for upscaling of results generated in WP3 of AGROMIX.

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11 References and citations

AGROSYNERGIE, 2013. Evaluation of the structural effects of direct support. Financed by the European Commission. Final report. Available at: http://ec.europa.eu/agriculture/evaluation/market-and-income-reports/structural-effects-directsupport-2013_en.htm

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

Ballin, M., Barcaroli, G., Masseli, M., Scarnó, M. (2018). Redesign sample for Land Use/Cover Area frame Survey (LUCAS) 2018. Eurostat, Luxembourg. doi: 10.2785/132365. Available online at: https://ec.europa.eu/eurostat/web/products-statistical-working-papers/-/KS-TC-18-006

Burgess PJ, den Herder M, Dupraz C, Garnett K, Giannitsopoulos M, Graves AR, Hermansen JE, Kanzler M, Liagre F, Mirck J, Moreno G, Mosquera-Losada MR, Palma JHN, Pantera A, Plieninger T (2018). AGFORWARD PROJECT Final Report. Cranfield University: AGFORWARD.

Coppola, E. et al. (2021). Assessment of the European Climate Projections as Simulated by the Large EURO-CORDEX 32 Regional and Global Climate Model Ensemble. Journal of Geophysical Research: Atmospheres, 126(4), 33 e2019JD032356.

Christensen, J.H. et al. (2013). Climate Phenomena and their Relevance for Future Regional Climate Change. In: 18 Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment 19 Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, 20 S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.)]. Cambridge University Press, 21 Cambridge, United Kingdom and New York, NY, USA, pp. 1217–1308.

d'Andrimont, R., Yordanov, M., Martinez-Sanchez, L, Eiselt, B. Palmieri, A., Dominici, P., Gallego, J., Reuter, H.I., Joebges, C., Lemoine, G., van der Velde, M. (2020). Harmonised LUCAS in-situ land cover and use database for field surveys from 2006 to 2018 in the European Union. Scientific Data, 7: 352. https://doi.org/10.1038/s41597-020-00675-z

Den Herder, M., Moreno, G., Mosquera-Losada, M.R., Palma, J.H.N., Sidiropoulou, A., Santiago Freijanes, J., Crous-Duran, J., Paulo, J., Tomé, M., Pantera, A., Papanastasis, V., Mantzanas, K., Pachana, P., Burgess, P.J. (2015). Current extent and trends of agroforestry in the EU27. Deliverable Report 1.2 for EU FP7 Research Project: AGFORWARD 613520. (4 December 2015). 99 pp. Available online: http://agforward.eu/index.php/en/current-extent-and-trends-of-agroforestry-in-the-eu27.html

Den Herder, M., 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. (2017). Current extent and stratification of agroforestry in the European Union. Agriculture, Ecosystems & Environment, 241, 121-132.

Doblas-Reyes, F.J., A.A. Sörensson, M. Almazroui, A. Dosio, W.J. Gutowski, R. Haarsma, R. Hamdi, B. Hewitson, W.-T. Kwon, B.L. Lamptey, D. Maraun, T.S. Stephenson, I. Takayabu, L. Terray, A. Turner, and Z. Zuo (2021). Linking Global to Regional Climate Change. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [MassonDelmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

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

Eichhorn, M.P., P. Paris, F. Herzog, L.D. Incoll, F. Liagre, K. Mantzanas, M. Mayus, G. Moreno, V.P. Papanastasis, D.J. Pilbeam, A. Pisanelli, C. Dupraz (2006). Silvoarable systems in Europe – past, present and future prospects. Agrofor. Syst., 67, 29-50, 10.1007/s10457-005-1111-7.

EIP-AGRI Focus Group on Mixed Farming Systems: livestock/cash crops (2017). Final Report. European Commission, Brussels.

European Environment Agency (2016). Biogeographical regions. Online source: https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3

Eurostat, (2013). LUCAS 2012 (Land Use / Cover Area Frame Survey). Technical Reference Document: C-1 Instructions for Surveyors. Eurostat, European Commission.

Eurostat, (2013). Data browser. Online source: https://ec.europa.eu/eurostat/databrowser/view/reg_area3/default/table?lang=en

Eurostat (2015). LUCAS 2015 (Land Use / Cover Area Frame Survey). Technical reference document C3 Classification. 2015.

Eurostat (2018). LUCAS 2018 (Land Use / Cover Area Frame Survey). Technical reference document C1, Instructions for Surveyors.

Eurostat (2019). LUCAS - Land use and land cover survey. Statistics Explained. Online source: https://ec.europa.eu/eurostat/statisticsexplained/

Eurostat (2021). LUCAS - Land use and land cover survey. Statistics Explained. Online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=LUCAS_-_Land_use_and_land_cover_survey

Eyring, V., N.P. Gillett, K.M. Achuta Rao, R. Barimalala, M. Barreiro Parrillo, N. Bellouin, C. Cassou, P.J. Durack, Y. Kosaka, S. McGregor, S. Min, O. Morgenstern, and Y. Sun (2021). Human Influence on the Climate System. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Fagerholm, N., Torralba, M., Burgess, P., Plieninger, T. (2016). A systematic map of ecosystem services assessments around European agroforestry. Ecological Indicators 62, 47-65.

Farm Accountancy Data Network (2010-2013) analysed by the European Commission and published 2015.

Fischer, E.M. and Knutti, R. (2016). Observed heavy precipitation increase confirms theory and early models, Nature Climate Change, 6(11), 986–991.

Forzieri, G. et al. (2014). Ensemble projections of future streamflow droughts in Europe. Hydrology and Earth System 61 Sciences, 18(1), 85–108

Forzieri, G. et al. (2016). Multi-hazard assessment in Europe under climate change. Climatic Change, 137(1–2), 105– 2 119.

Giorgi, F. and Francisco, R. (2000). Uncertainties in regional climate change prediction: a regional analysis of ensemble simulations with the HADCM2 coupled AOGCM, Clim. Dynam., 16, 169–182.

Giorgi, F., Hewitson, B., Christensen, J., Hulme, M., Storch, H. V., Whetton, P., Jones, R., Mearns, L., and Fu, C.: Climate Change (2001). The Scientific Basis, edited by: Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., vad der Linden, P. J., Dai, X., Maskell, K., and Johnson, C. A., Regional Climate Information, Evaluation and Projections, 583–638, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2001.

Guerreiro, S.B., R.J. Dawson, C. Kilsby, E. Lewis, and A. Ford (2018). Future heat-waves, droughts and floods in 571 European cities, Environmental Research Letters, 13(3), 034009, doi:10.1088/1748-9326/aaaad3.

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

Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I.V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon (2021). Atlas. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Gutowski, W.J. et al. (2016). WCRP COordinated Regional Downscaling EXperiment (CORDEX): a diagnostic MIP 38 for CMIP6. Geoscientific Model Development, 9(11), 4087–4095.

IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Iturbide, M., Gutiérrez, J. M., Alves, L. M., Bedia, J., Cerezo-Mota, R., Cimadevilla, E., Cofiño, A. S., Di Luca, A., Faria, S. H., Gorodetskaya, I. V., Hauser, M., Herrera, S., Hennessy, K., Hewitt, H. T., Jones, R. G., Krakovska, S., Manzanas, R., Martínez-Castro, D., Narisma, G. T., Nurhati, I. S., Pinto, I., Seneviratne, S. I., van den Hurk, B., and Vera, C. S. (2020). An update of IPCC climate reference regions for subcontinental analysis of climate model data: definition and aggregated datasets, Earth Syst. Sci. Data, 12, 2959–2970.

Jensletten, J.L. and Klokov, K. (2002). Sustainable Reindeer Husbandry. Arctic Council 2000 – 2002, Centre for Saami Studies, University of Tromsø.

Knutson, T.R. and Zeng, F. (2018). Model assessment of observed precipitation trends over land regions: Detectable 59 human influences and possible low bias in model trends. Journal of Climate, 31(12), 4617–4637.

Kovats, R.S., R. Valentini, L.M. Bouwer, E. Georgopoulou, D. Jacob, E. Martin, M. Rounsevell, and J.-F. Soussana (2014). Europe. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1267-1326.

Lawson, G., Dupraz, C., Watté, J. (2019). Can Silvoarable Systems Maintain Yield, Resilience, and Diversity in the Face of Changing Environments? In: Agroecosystem Diversity. Reconciling Contemporary Agriculture and Environmental Quality. Academic Press pp. 145-168.

Leterme, P. et al. (2016) CANTOGETHER – Project Final Report. Institut National de la Recherche Agronomique (INRA).

McAdam, J., Burgess, P., Graves, A., Riguero-Rodríquez A., Mosquera-Losada, M. (2009). Classifications and functions of agroforestry systems in Europe. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada, M. (eds) Agroforestry in Europe: Current Status and Future Prospects. Springer Science + Business Media B.V., Dordrecht, p. 21–42.

Mora, C. et al. (2018). Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas 37 emissions. Nature Climate Change, 8(12), 1062–1071, doi:10.1038/s41558-018-0315-6.

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

Moraine, M., Duru, M., Nicholas. P., Leterme, P. and Therond, O. (2014) Farming system design for innovative crop-livestock integration in Europe. Animal, 8:8, 1204–1217. doi:10.1017/S1751731114001189.

Mosquera-Losada, M.R., McAdam J., Romero-Franco, R., Santiago-Freijanes, J.J., Riguero-Rodríquez A. (2009). Definitions and components of agroforestry practices in Europe. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada, M. (eds) Agroforestry in Europe: current status and future prospects. Springer Science + Business Media B.V., Dordrecht, p. 3-19.

Mosquera-Losada, M.R., Santiago-Freijanesa,J.J., Rois-Díaza, M., Moreno, G., den Herder, M. J.A. Aldrey-Vázquez, J.A., Ferreiro-Domíngueza, N., Panteraf, A., Pisanellig, A., Rigueiro-Rodríguez, A. (2018). Agroforestry in Europe: A land management policy tool to combat climate Change. Land Use Policy, 78, 603-613. doi.org/10.1016/j.landusepol.2018.06.052**.**

Pimbert, M. (2015). Agroecology as an Alternative Vision to Conventional Development and Climate-smart Agriculture. Development 58, 286-298.

Plieninger, T., Hartel, T., Martín-López, B., Beaufoy, G., Bergmeier, E., Kirby, K., Montero, M.J., Moreno, G., Oteros-Rozas, E., Van Uytvanck, J. (2015). Wood-pastures of Europe: Geographic coverage, social–ecological values, conservation management, and policy implications, Biological Conservation 190: 70-79. doi: 10.1016/j.biocon.2015.05.014.

Prein, A.F. et al. (2016). Precipitation in the EURO-CORDEX 0.11° and 0.44° simulations: high resolution, high benefits? Climate Dynamics, 46(1–2), 383–412.

Püttsepp, Ü. Schnabel, S., Antichi, D. Chiron, G., Dehnen-Schmutz, K. Hensoo, K., Kauer, K., Mele, M., Ots, M., Pechenart, E. Tali, K., Venn, R., Verstand, D. (2020). Handbook of resilience and working definitions. AGROMIX D1.1 project report.

Ranasinghe, R., A.C. Ruane, R. Vautard, N. Arnell, E. Coppola, F.A. Cruz, S. Dessai, A.S. Islam, M. Rahimi, D. Ruiz Carrascal, J. Sillmann, M.B. Sylla, C. Tebaldi, W. Wang, and R. Zaaboul (2021). Climate Change Information for Regional Impact and for Risk Assessment. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [MassonDelmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Ruosteenoja, K., T. Markkanen, A. Venäläinen, P. Räisänen, and H. Peltola (2018). Seasonal soil moisture and drought 29 occurrence in Europe in CMIP5 projections for the 21st century. Climate Dynamics, 50(3–4), 1177–1192, 30 doi:10.1007/s00382-017-3671-4

Seneviratne, S.I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, I. Iskandar, J. Kossin, S. Lewis, F. Otto, I. Pinto, M. Satoh, S.M. Vicente-Serrano, M. Wehner, and B. Zhou (2021). Weather and Climate Extreme Events in a Changing Climate. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [MassonDelmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Spinoni, J., J. Vogt, G. Naumann, P. Barbosa, and A. Dosio (2018). Will drought events become more frequent and severe in Europe? International Journal of Climatology, 38(4), 1718–1736, doi:10.1002/joc.5291.

Tsonkova, P., C. Böhm, A. Quinkenstein, D. Freese (2012). Ecological benefits provided by alley cropping systems for production of woody biomass in the temperate region: a review. Agrofor. Syst., 85, 133-152. 10.1007/s10457-012-9494-8.

Wilson, M., Lovell, S. (2016). Agroforestry—The Next Step in Sustainable and Resilient Agriculture. Sustainability 8, 574.

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12 Annex

Annex 1A. Field crops combined with grazing livestock (km^2) for European member states for 2005, 2007, 2010 and 2013, as well as the difference and percentage difference between 2005 and 2013 (data extracted from EUROSTAT).

Country	2005	2007	2010	2013	Difference	%difference
Austria	857	824	851	964	107	12.5
Belgium	1865	1838	1723	1486	-379	-20.3
Bulgaria	1564	1944	1298	1210	-354	-22.6
Cyprus	30	27	24	12	-18	-60.4
Czechia	10244	10140	10089	10144	-101	-1.0
Denmark	1417	1372	1233	1242	-175	-12.3
Estonia	630	554	627	631	1	0.1
Finland	545	537	556	588	43	7.9
France	27003	27161	27615	29995	2992	11.1
Germany	24191	23452	20648	21639	-2552	-10.5
Greece	1296	1155	902	694	-602	-46.5
Hungary	4203	3694	4357	4602	399	9.5
Ireland	1552	1183	1329	1472	-80	-5.2
Italy	2626	2560	2749	2820	194	7.4
Latvia	1971	1874	1841	1990	20	1.0
Lithuania	3853	3835	3460	3843	-10	-0.3
Luxembourg	77	72	82	83	6	8.3
Malta	0	0	0	1	1	100.0
Netherlands	492	446	416	380	-112	-22.7
Poland	12356	11765	15056	15615	3259	26.4
Portugal	1963	1553	1630	1374	-589	-30.0
Romania	11496	11173	3225	4461	-7035	-61.2
Slovakia	4573	4687	4363	4354	-220	-4.8
Slovenia	115	134	153	169	54	46.7
Spain	7660	7111	8364	8498	839	10.9
Sweden	2030	1779	1951	1826	-204	-10.0
United Kingdom	10459	10163	9314	9881	-577	-5.5
Total	**135065**	**131032**	**123855**	**129972**	**-5093**	**-3.8**

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Annex 1B. Various crops combined with livestock (km²) for European member states for 2005, 2007, 2010 and 2013, as well as the difference and percentage difference between 2005 and 2013 (data extracted from EUROSTAT).

Country	2005	2007	2010	2013	Difference	%difference
Austria	899	845	806	1053	154	17.2
Belgium	369	367	353	388	18	5.0
Bulgaria	1154	1228	713	506	-648	-56.1
Cyprus	47	49	32	33	-14	-29.9
Czechia	4202	3670	2613	1879	-2323	-55.3
Denmark	1834	1768	1859	1366	-467	-25.5
Estonia	293	262	239	235	-58	-19.7
Finland	529	567	590	626	98	18.5
France	6845	6188	5604	5235	-1611	-23.5
Germany	10948	10793	9235	8831	-2117	-19.3
Greece	3405	3304	2482	1671	-1734	-50.9
Hungary	4677	4120	3537	2955	-1721	-36.8
Ireland	161	108	47	54	-107	-66.3
Italy	4281	3923	2711	2786	-1495	-34.9
Latvia	1913	1572	789	888	-1026	-53.6
Lithuania	3792	2566	1892	1491	-2301	-60.7
Luxembourg	17	22	16	17	0	0.6
Malta	7	4	4	4	-3	-41.5
Netherlands	419	400	387	336	-83	-19.8
Poland	21041	20586	18916	14688	-6354	-30.2
Portugal	3246	2843	3373	3348	102	3.1
Romania	16505	14911	12638	10453	-6052	-36.7
Slovakia	1968	1492	881	750	-1218	-61.9
Slovenia	528	489	511	522	-7	-1.2
Spain	6434	6230	4866	4131	-2303	-35.8
Sweden	901	818	738	678	-224	-24.8
United Kingdom	1817	1742	1775	1855	38	2.1
Total	**98233**	**90864**	**77609**	**66779**	**-31454**	**-32.0**

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Annex 2. Land cover codes based on LUCAS databases.

CODE	DESCRIPTION
8	Not relevant
GRAZING	**1 = grazing areas; 2 = no grazing areas; 8 = not relevant**
A00 ARTIFICIAL LAND	
A10 ROOFED BUILT-UP AREAS	
A11	Buildings with 1 to 3 floors
A12	Buildings with more than 3 floors
A13	Greenhouses
A20 ARTIFICIAL NON BUILT-UP AREAS	
A21	Non built-up area features
A22	Non built-up linear features
A30	Other artificial areas
B00 CROPLAND	
B10 Cereals	
B11	Common wheat
B12	Durum wheat
B13	Barley
B14	Rye
B15	Oats
B16	Maize
B17	Rice
B18	Triticale
B19	Other cereals
B20 Root crops	
B21	Potatoes
B22	Sugar beet
B23	Other root crops
B30 Non-permanent industrial crop	
B31	Sunflower
B32	Rape and turnip rape
B33	Soya
B34	Cotton
B35	Other fibre and oleaginous crops
B36	Tobacco
B37	Other non-permanent industrial crops
B40 Dry pulses, vegetables and flowers	
B41	Dry pulses
B42	Tomatoes
B43	Other fresh vegetables
B44	Floriculture and ornamental plants
B45	Strawberries
B50 Fodder crops	
B51	Clovers
B52	Lucerne
B53	Other leguminous and mixtures for fodder
B54	Mixed cereals for fodder
B55	Temporary grasslands
B70 Permanent crops: Fruit trees	
B71	Apple fruit
B72	Pear fruit
B73	Cherry fruit
B74	Nuts trees

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B75	Other fruit trees and berries
B76	Oranges
B77	Other citrus fruit
B80 Other permanent crops	
B81	Olive groves
B82	Vineyards
B83	Nurseries
B84	Permanent industrial crops
Bx1	Arable land (only PI)
Bx2	Permanent crops (only PI)
C00 WOODLAND	
C10	Broadleaved woodland
C20 Coniferous woodland	
C21	Spruce dominated coniferous woodland
C22	Pine dominated coniferous woodland
C23	Other coniferous woodland
C30 Mixed woodland	
C31	Spruce dominated mixed woodland
C32	Pine dominated mixed woodland
C33	Other mixed woodland
D00 SHRUBLAND	
D10	Shrubland with sparse tree cover
D20	Shrubland without tree cover
E00 GRASSLAND	
E10	Grassland with sparse tree/shrub cover
E20	Grassland without tree/shrub cover
E30	Spontaneously vegetated surfaces
F00 BARE LAND AND LICHENS/MOSS	
F10	Rocks and stones
F20	Sand
F30	Lichens and moss
F40	Other bare soil
G00 WATER AREAS	
G10 Inland water bodies	
G11	Inland freshwater bodies
G12	Inland salty water bodies
G20 Inland running water	
G21	Inland fresh running water
G22	Inland salty running water
G30	Transitional water bodies
G40	Marine sea
G50	Glaciers, permanent snow
H00 WETLANDS	
H10 Inland wetlands	
H11	Inland marshes
H12	Peatbogs
H20 Coastal wetlands	
H21	Salt marshes
H22	Salines and other chemical deposits
H23	Intertidal flats

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Annex 3: Land use codes based on LUCAS databases.

CODE	DESCRIPTION
8	Not relevant
U100	**PRIMARY SECTOR**
U110	AGRICULTURE
U111	Agriculture (excluding fallow land and kitchen gardens)
U112	Fallow land
U113	Kitchen garden
U120	FORESTRY
U130	AQUACULTURE AND FISHING
U140	MINING AND QUARRYING
U150	OTHER PRIMARY PRODUCTION
U200	**SECONDARY SECTOR**
U210	ENERGY PRODUCTION
U220	INDUSTRY AND MANUFACTURING
U221	Manufacturing of food, beverages and tobacco products
U221L	Manufacture of food beverages or tobacco products (light end)
U222	Manufacturing of textile products
U222R	Manufacturing of textile products (raw)
U222L	Manufacturing of textile products (light end)
U223	Coal, oil and metal processing
U223R	Coal, oil and metal processing (raw)
U223H	Coal, oil and metal processing (heavy end)
U224	Production of non-metal mineral goods
U224R	Production of non-metal mineral goods (raw)
U225	Chemical and allied industries and manufacturing
U225R	Chemical and allied industries and manufacturing (raw)
U225L	Chemical and allied industries and manufacturing (light end)
U226	Machinery and equipment
U226H	Machinery and equipment (heavy end)
U226L	Machinery and equipment (light end)
U227	Wood based products
U227R	Wood based products (raw)
U228	Printing and reproduction
U228L	Printing and reproduction (light end)
U300	**TERTIARY SECTOR, TRANSPORT, UTILITIES AND RESIDENTIAL**
U310	TRANSPORT, COMMUNICATION NETWORKS, STORAGE, PROTECTION WORKS
U311	Railway transport
U312	Road transport
U313	Water transport
U314	Air transport
U315	Transport via pipelines
U315W	Transport of water via pipelines
U315O	Transport of other material via pipelines
U316	Telecommunication
U317	Logistics and storage
U318	Protection infrastructures
U319	Electricity, gas and thermal power distribution
U320	WATER AND WASTE TREATMENT
U321	Water supply and treatment
U322	Waste treatment
U330	CONSTRUCTION

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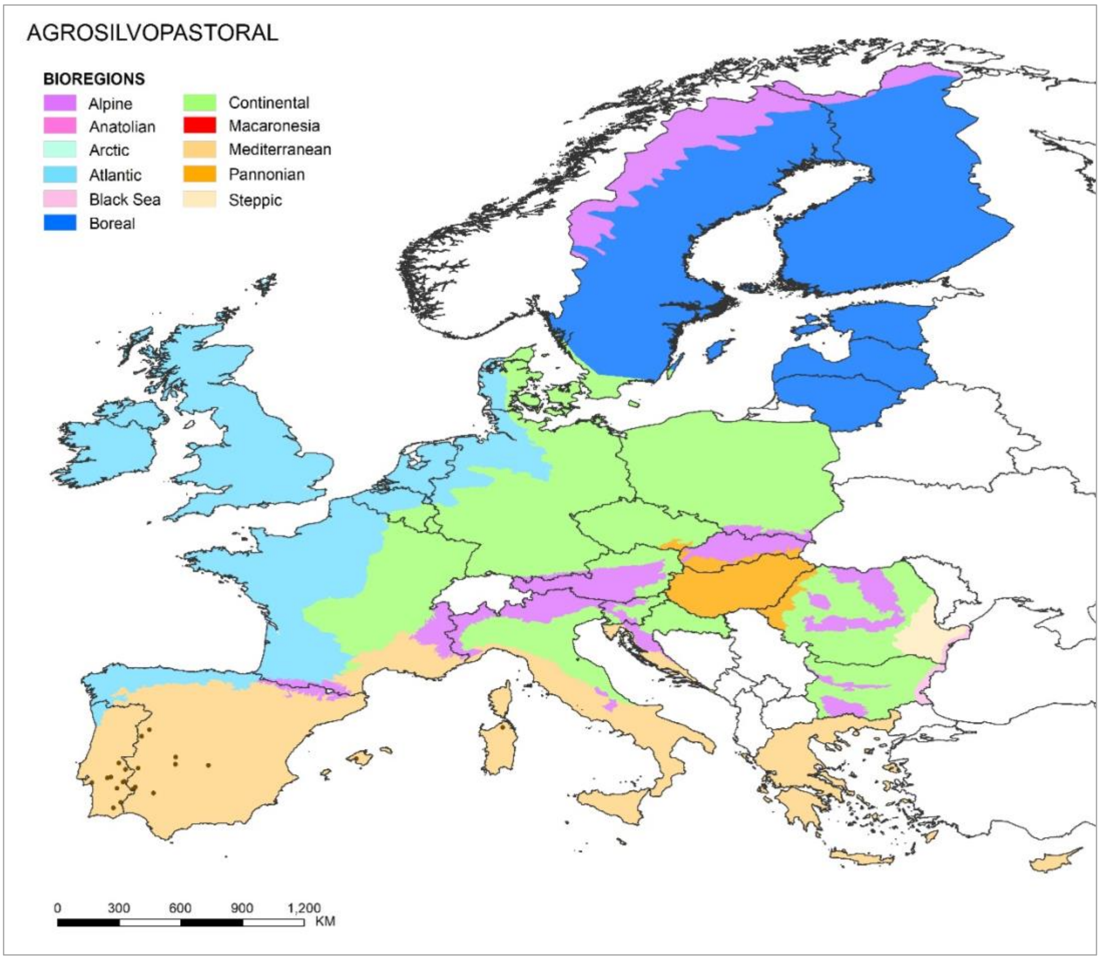
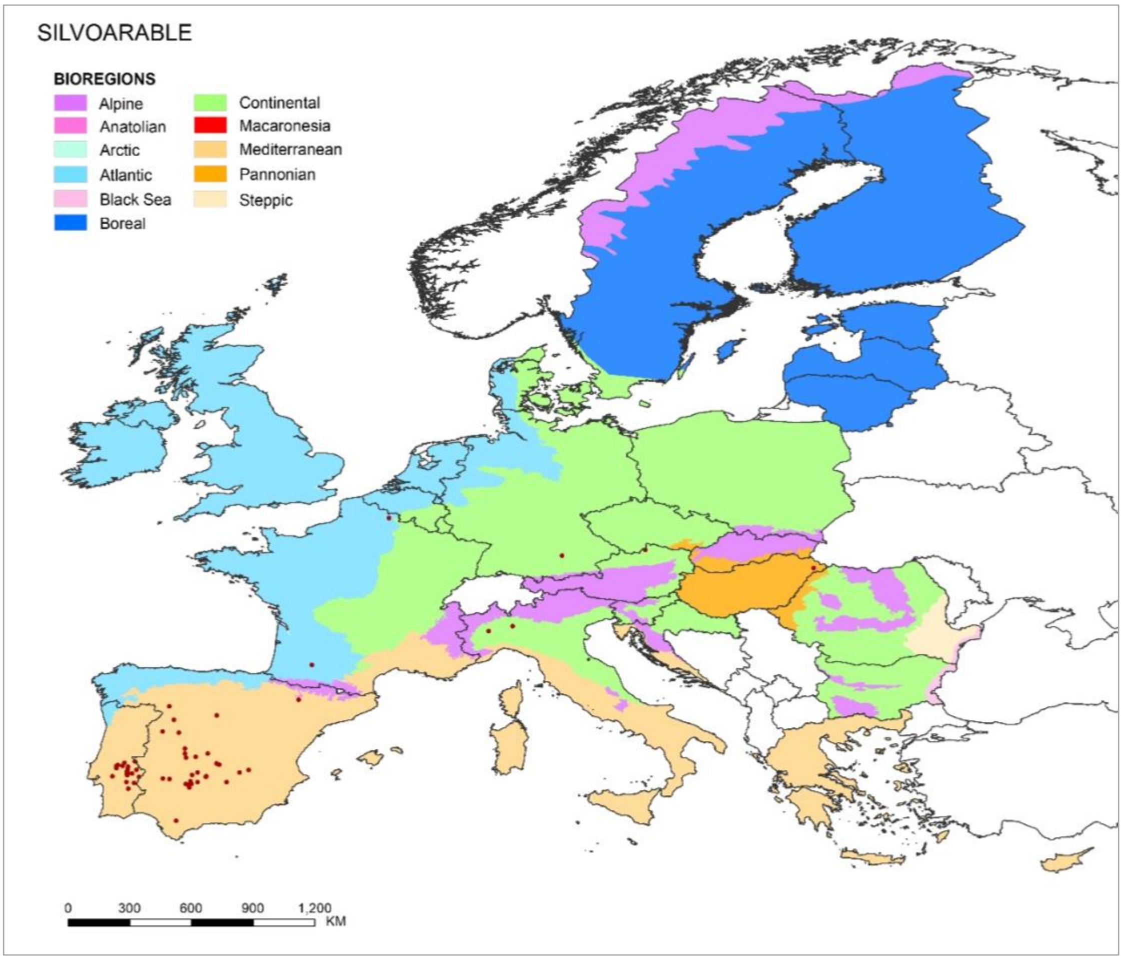
U340	COMMERCE, FINANCIAL, PROFESSIONAL AND INFORMATION SERVICES
U341	Commerce
U342	Financial, professional and information services
U350	COMMUNITY SERVICES
U360	RECREATION, LEISURE, SPORT
U361	Amenities, museums, leisure
U362	Sport
U370	RESIDENTIAL
U400	**UNUSED AND ABANDONED AREAS**
U410	ABANDONED AREAS
U411	Abandoned industrial areas
U412	Abandoned commercial areas
U413	Abandoned transport areas
U414	Abandoned residential areas
U415	Other abandoned areas
U420	SEMI-NATURAL AND NATURAL AREAS NOT IN USE

Annex 4: Point distribution of agrosilvopastoral systems in EU-28 by biogeographical regions



Annex 5: Silvoarable crops in EU-28 by bioregions (2018).



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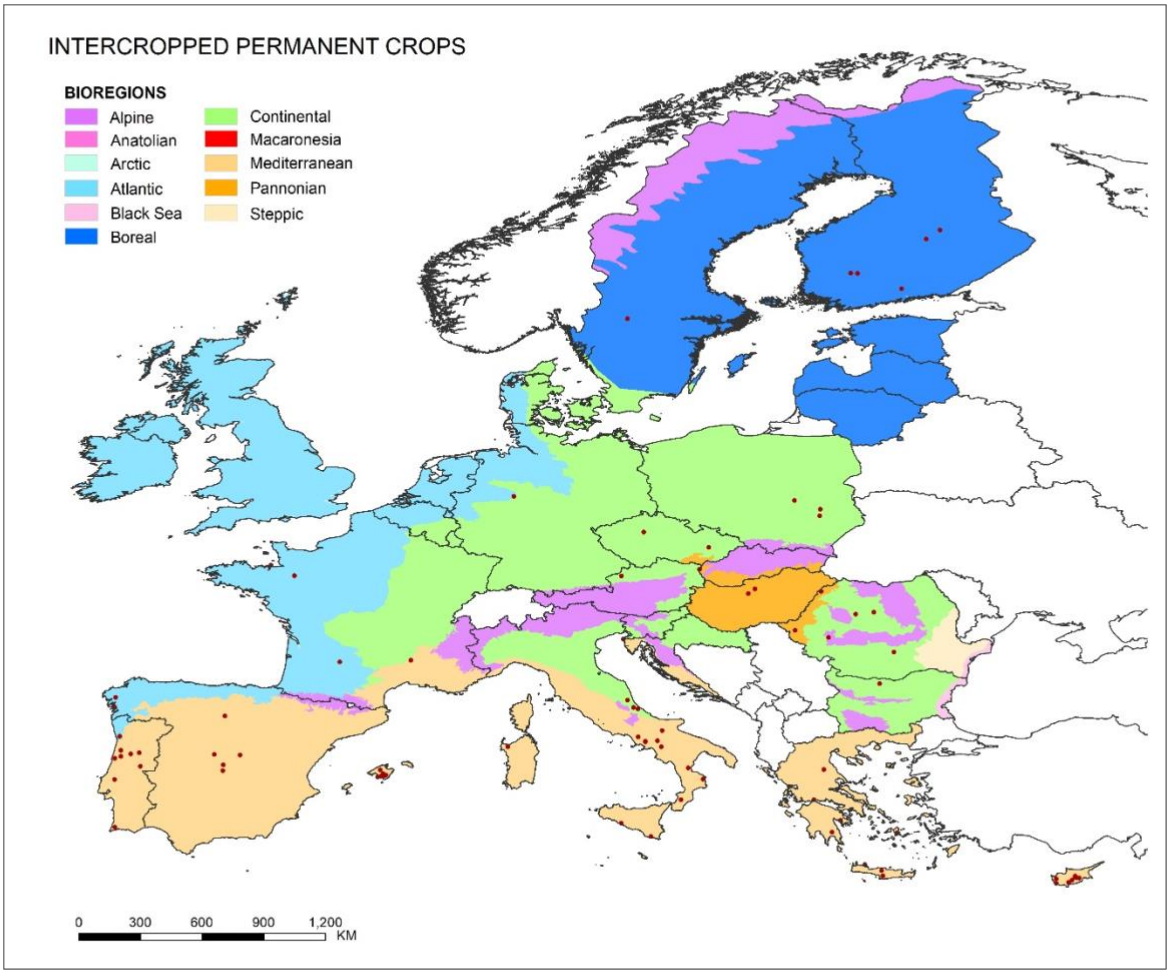
Annex 6: Intercropped permanent crops in EU-28 by biogeographical regions (survey 2018).



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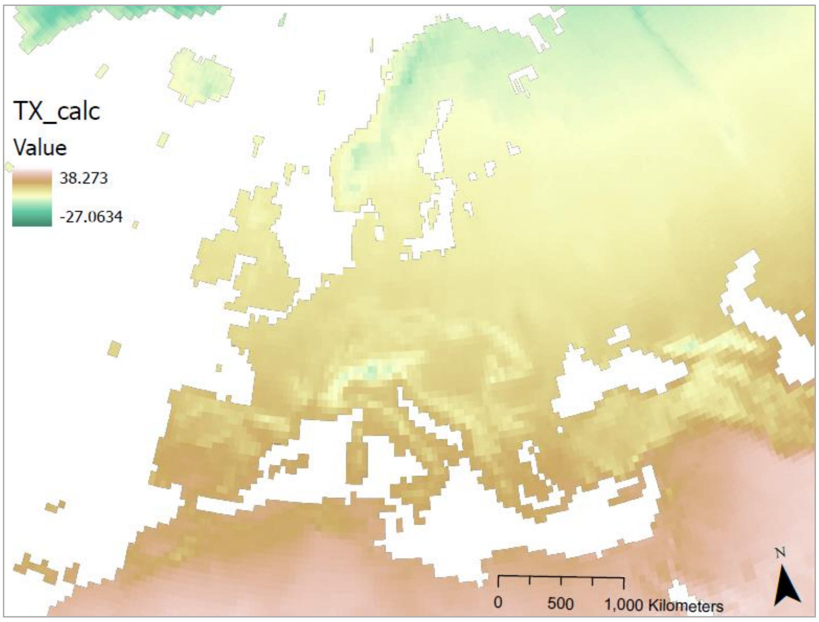
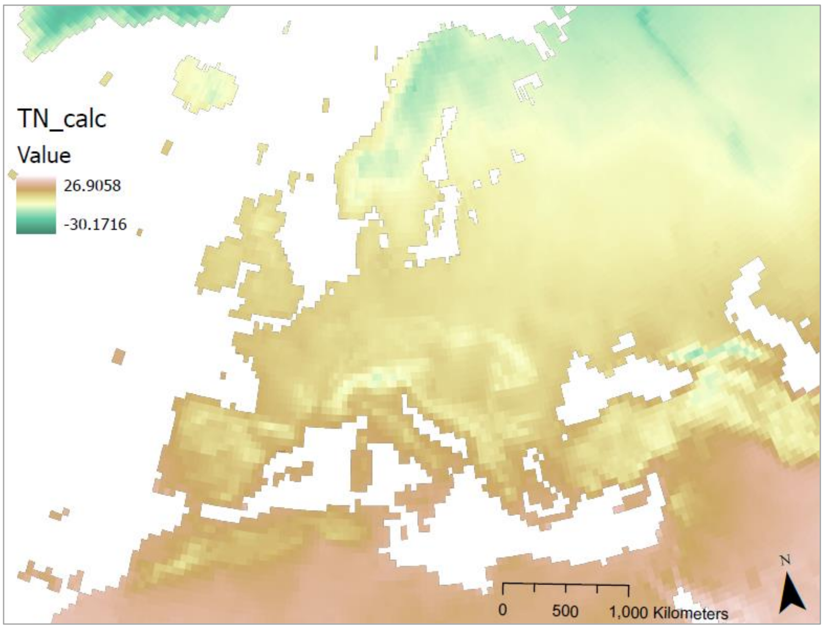
Annex 7: Annual maximum temperature. Note: Values represent the mean of dekadal (10 days) mean maximum temperature.



Annex 8: Annual minimum temperature. Note: Values represent the mean of dekadal (10 days) mean minimum temperature.



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