Report

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EUROSTAT
European Commission

Sub-Task 2.3

T 2.3

Analysis of LUCAS information related to Agroforestry

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1 Overview of existing information on agroforestry

1.1 Foreword

The aim of the subtask 2.3 is to analyse the agroforestry information available within the LUCAS surveys to perform area estimations and support the information needs of DG AGRI using the LUCAS surveys 2009-2018. Available data for the agroforestry classes resulted in a too sparse dataset and preliminary calculations did not provide reliable estimates for trend analysis. Therefore, no trend analysis over time was completed as part of this subtask.

The activity was piloted with the last LUCAS survey (2018), which benefits from the availability of additional variables missing from the previous surveys. Among these, the EUNIS Habitat Complex Module is the most relevant to collect agroforestry information. After consolidating the procedures, the work was extended to the previous LUCAS campaigns (2009, 2012 and 2015). The estimates concern the status for the surveys years (2009-2018) at different NUTS levels (0, 1, 2 and 3).

The results were computed for the 2016 version of the Nomenclature of Territorial Units for Statistics (NUTS). On 1 January 2021, the new NUTS 2021 classification came into force. The task results obtained from the modelling exercises cannot be extrapolated for the statistical regions in 2021, as the available data are based on NUTS 2016.

In the following chapters, some aspects are not fully described since they have already been documented in the report on Subtask 2.1 (i.e., description of the LUCAS datasets and variables, the LUCAS Master Grid and the covariates already used in Subtask 2.1).

Objectives from the task description

- to establish a set of rules for extracting LUCAS survey points representative of the main agroforestry systems;
- to assess the spatial distribution and areal extent of agroforestry systems for specific statistical units (NUTS) using a model-based approach;
- to assess the temporal trend (not carried out due to the low reliability of the estimates) and spatial distribution using the multi-annual LUCAS datasets;
- to analyse the quality of the area estimates.

Activities for Subtask 2.3 were carried out in the period from 1 May 2021 to 31 January 2022.

1.2 Definition of agroforestry

Agroforestry (AF) systems have important impacts in terms of ecosystem services and biodiversity while contributing to farm income in the EU. However, it is clearly difficult to map and quantify the areal extent of AF as there is no common EU definition in land use and agricultural statistics. The issue is also of great importance for the Common Agricultural Policy (CAP), as such a management system contributes to the achievement of environmental policy objectives. AF systems are sustainable and multifunctional and provide many environmental benefits (climate change adaptation and mitigation, soil protection, biodiversity enhancement). Cultural and economic benefits are also recognised (growth of local rural economies and cultural and recreational opportunities). Farmers can also diversify and improve their production. The current CAP helps to maintain AF systems through direct payments per hectare of AF land and through rural development support. The European Parliament has recognised the benefits of AF in several resolutions and called for more effective support for a range of sustainable production methods, including AF. In the new CAP, AF potential and benefits are highlighted in the draft Strategic Plan Regulation, and in the Farm to Fork Strategy and Biodiversity Strategies, all of which fall within the framework of the European Green Deal.

Several definitions of AF systems have been formulated so far. In general, AF is the deliberate integration of woody vegetation (trees or shrubs) into crop and/or animal production systems to benefit from the resulting ecological and economic interactions (Mosquera-Losada et al., 2009). Further definitions are provided by the European Commission (2013), according to which AF comprises *“land use systems in which trees are grown in combination with agriculture on the same land”*. Furthermore, FAO (2015) defines it as *“land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence”.*

Very few attempts have been made in the literature to assess the spatial distribution and areal extent of AF in Europe using LUCAS Surveys datasets. These works use a combination of LUCAS Survey variables to define rules for extracting eligible AF points, although the definition and scope of AF may vary (see Den Herder et al., 2017 and Plieninger et al., 2015). Regarding primary data collection, Eurostat made an attempt to characterise AF areas attempt with the last LUCAS Survey (2018) by adding a specific module (EUNIS Habitat Complex) to collect AF information for each point surveyed.

As part of this task, a new simplified definition of AF (see table below) was elaborated by DG AGRI and Eurostat after reviewing the relevant literature, studying the results of the EUNIS module and analysing the field photos for different LUCAS samples, taking into account the following aspects:

- Identification of extensive orchards with grazing or the presence of animals without grassland as secondary land cover to avoid the inclusion of normal specialised orchards.
- Identification of high value trees (e.g., fruit trees) with arable crops to cover extensive orchards.
- Identification of woodland and shrubland with arable crops to cover sparse forestland with arable crops.
- Identification of LUCAS points classified as EUNIS X06 (cultivated trees with secondary crops, meadows, or pastures) or X09 (forest trees with grazed grassland, heathland and/or woodland flora).

- No distinction was made between AF features at field and landscape level, and plot size conditions were not included.

Table 1 – Definition of AF classes used to characterize AF systems across Europe.

AF class	Definition
Grazed orchards (GRAZED_O)	Areas with permanent crops (i.e., fruit trees, olive groves and vineyards) having visible signs of grazing with a primary or secondary agricultural land use.
Arable high value trees (ARABLE_T)	Areas with permanent crops (i.e., as fruit trees, olive groves and vineyards) intercropped with arable crops (i.e., cereals, root crops, some industrial crops, dry pulses, vegetables, flowers, and fodder crops) with a primary agricultural land use.
Agroforestry for arable systems (ARABLE_S)	Areas with woodland and shrubland with sparse trees intercropped with arable crops (i.e., cereals, root crops, some industrial crops, dry pulses, vegetables, flowers, and fodder crops) with a primary or secondary agricultural land use.
Agroforestry for livestock systems (LIVESTOCK_S)	Areas with woodland and shrubland with sparse tree cover with a primary or secondary agricultural or agroforestry land use.

1.3 AF and LUCAS EUNIS Habitat Complex

The new EUNIS Habitat Complex module, introduced with the 2018 LUCAS Survey, allows classifying points in terms of AF. The occurrence of AF at LUCAS survey points is assessed by surveyors on the homogenous plot within the extended window of observation for points with trees (including permanent crops). The points can be assigned to the following two different habitats:

- X06 - Cultivated trees with secondary crops, meadow or pasture
  Crops, meadows or pastures developed under orchards or other cultivated tree plantations;
- X09 - Forest trees with grazed grassland, heathland and/or woodland flora
  Pasture woods (with a tree layer overlying pasture) with forest trees. Large, open-grown, or high forest trees (often pollards) at various densities, in a matrix of grazed grassland.

The results of the module were extensively validated, therefore, the EUNIS classification was essentially used for data exploration and to better assess the performances of the different rules tested for the AF classes. In addition, a preliminary analysis on the reliability of EUNIS classification was performed by analysing the LUCAS variables for a sample of points classified as X06 and X09. The reliability analysis of the classification was also supported by a thorough visual analysis of a set of 127 points in total. The results showed that the error rate, where X06 (6 out of 62 not correct) or X09 (6 out of 65 not correct) were not correctly assessed was around 10% for both classes. By presenting landscape photos of some exemplary points, GOPA was also able to show the variety of different types of landscapes, which are all correctly assessed with a EUNIS class. These practical examples of assessed data increased knowledge of the topic and led to discussions which allowed to improve and fine-tune the module of the next LUCAS Survey in 2022.

The results of data exploration for the 2018 LUCAS survey points (X06 and X09) are presented below.

Figure 1 – Number of points classified as X06 or X09 at EU level. The total number of points at EU level is 5784. (LUCAS Survey 2018).

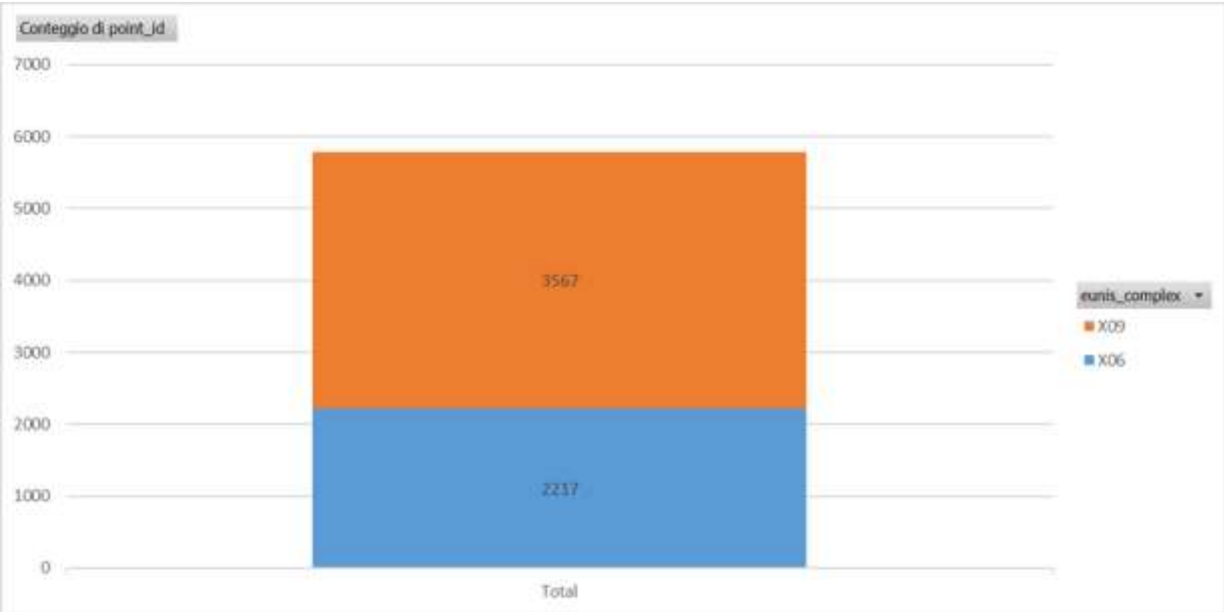

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Figure 2 - Percentage of points classified as X06 or X09 over the country total (LUCAS Survey 2018).

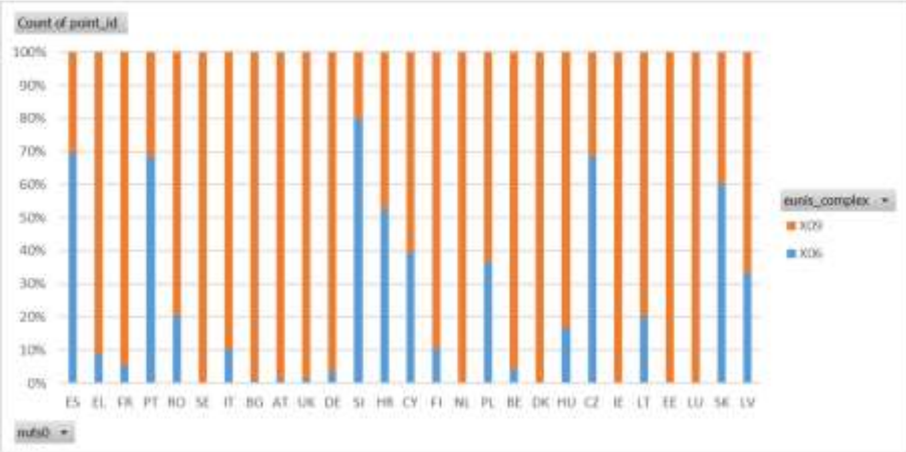


Figure 3 - Percentage of points classified as X06 by LC1 over the EU total (LUCAS Survey 2018).

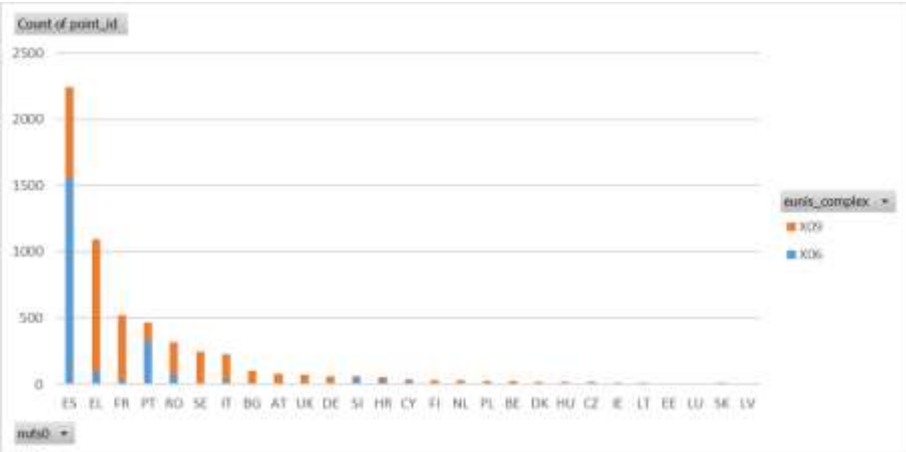
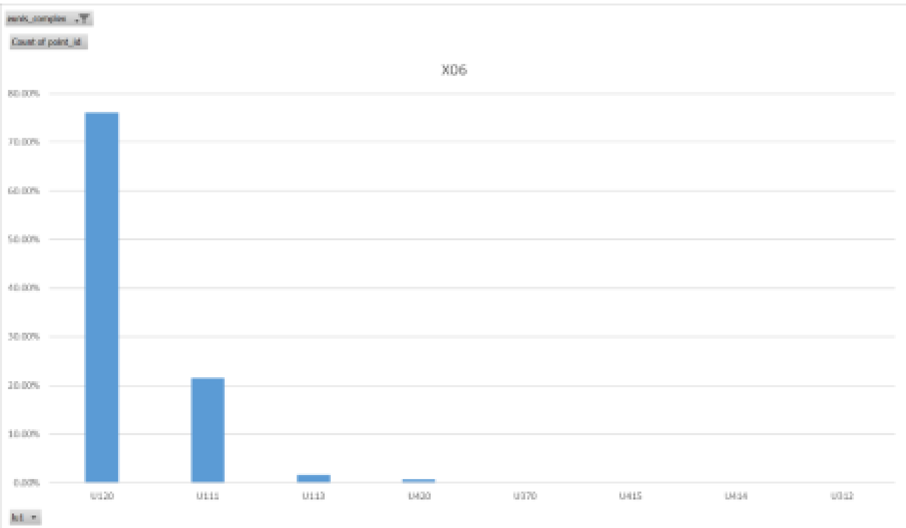


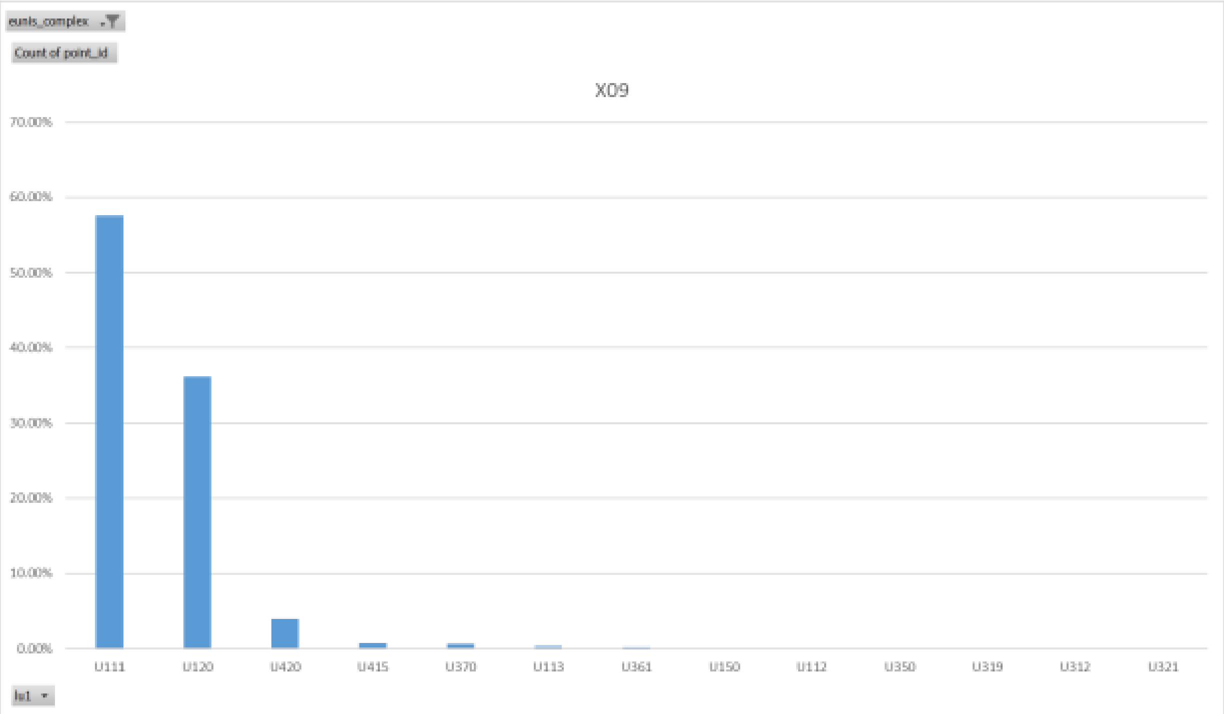
Figure 4 - Percentage of points classified as X09 by LC1 over the EU total (LUCAS Survey 2018).



Nearly 75% of the EUNIS X06 points have the main LC (LC1) equal to C10 (Broadleaved Woodland). There is a clear overlap with the points classified as Permanent Grassland (PG) and Other Grassland (OG), based on the rules for the selection of LUCAS grassland points in Task 2.1. The LC distribution is strongly affected by the classification of points from ES and PT, as they have a large number of points classified as AF. If the ES and PT points are removed, the LC1 is dominated by B70 (Permanent crops: fruit trees) and B80 (Other permanent crops), which together account for 87% of the points.

The predominant LC1 for X09 are quite diverse, including C10 (Broadleaved woodland) (39%), E10 (Grassland with sparse trees/shrub cover) (31%) and D10 (Shrubland with sparse tree cover) (13%), as well as other minor LC1.

Figure 5 - Percentage of points classified as X06 by LU1 over the EU total (LUCAS Survey 2018).

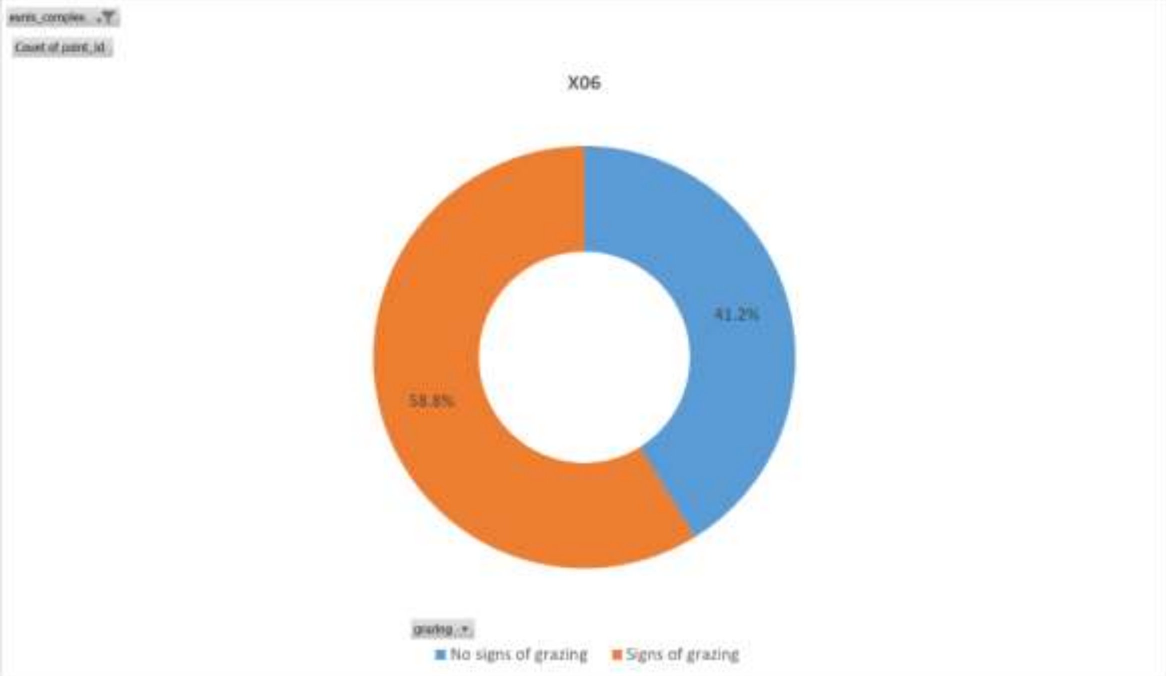


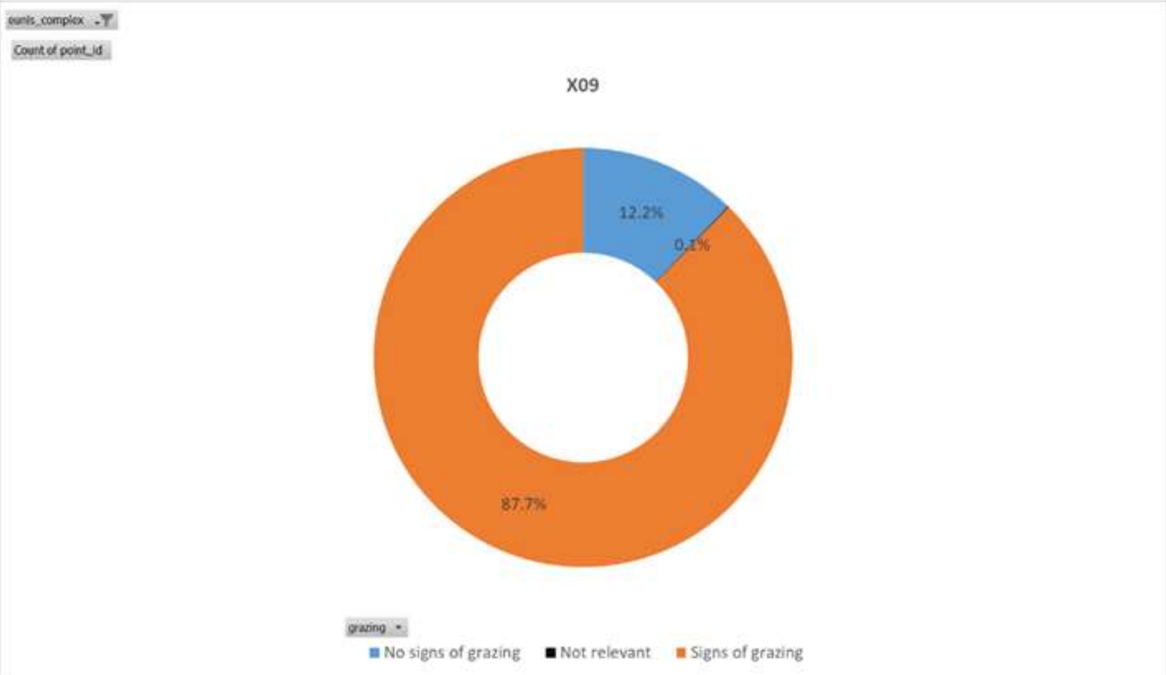
Concerning LU, the primary LU (LU1) for almost all points is U120 (Forestry) or U111 (Agriculture) when looking at classes X06 or X09. When the focus switches to the X06 class, the share of U120 is 76% and of U111 22%, while for X09 agricultural LU dominates over forestry LU (58% and 36%, respectively). The LU1 distribution changes drastically for X06 only when points are removed from ES and PT resulting in 82% of the points of the remaining countries being classified as U111.

When the variable on the occurrence of grazing is considered, about 59% of the points classified as X06 show signs of grazing; this percentage increases to about 88% for the points classified as X09.

Figure 6 - Percentage of points classified X06 with or without signs of grazing at EU level (LUCAS Survey 2018).

Figure 7 - Percentage of points classified X09 with or without signs of grazing at EU level (LUCAS Survey 2018).





1.1 AF classes from literature: rules and eligible LUCAS 2018 Survey points

Quite varied definitions of AF classes can be found in the literature. In general, both narrow and broad definitions are available, leading to different estimates of the corresponding areas at European and national level. The definition adopted in den Herder et. al, 2017 was analysed in terms of the type of LUCAS survey variables considered for each class, the total number of LUCAS survey points eligible for 2018 for each class and overlaps with the EUNIS classification. The analysis allowed a better alignment of the final definition agreed with Eurostat, based on DG AGRI feedback, and the rules selected for extracting LUCAS survey points for each class over the whole series of campaigns (2009-2018). It should be noted that the definition adopted in the current work is more restrictive than that of den Herder et. al, 2017, resulting in a lower number of eligible points for certain classes (i.e., Agroforestry for arable systems and Agroforestry for livestock systems) and for AF as a whole (3276 vs. 6963 LUCAS 2018 survey points). In particular, the rules adopted in this task filter out points without primary or secondary LU classified as agriculture or forestry.

Table 2 – LUCAS survey variables considered by den Herder *et. al*, 2017 for the different AF classes.

Class	Subclass	LUCAS variable			No. of LUCAS 2018 Survey points	No. of LUCAS 2018 EUNIS Survey points (X06 or X09)
		LC1	LC2	Grazing		
Agroforestry with high value trees	Grazed orchards	B71-B77, B81, B82, B84k	-	yes	297	221
	Arable high value tree	B71-B77, B81, B82, B84k	B11-B16, B19, B21, B23, B31, B41-B45, B51-B54	no	88	49
Agroforestry for arable systems	-	B71-B77, B81, B82, B84k, B84m, C10-C33, D10	B11-B16, B19, B21, B23, B31, B41-B45, B51-B54	no	166	118
Agroforestry for livestock systems	-	B71-B77, B81, B82, B84k, B84m, C10-C33, D10, E10	-	yes	6823	4433
Total agroforestry (removing overlaps between AF classes)					**6963**	**5784**

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1.2 Rules for selecting LUCAS survey points for the AF classes

The following table summarises the rules defined for the different AF classes: Grazed orchards, Arable high value trees, Agroforestry for arable systems and Agroforestry for livestock systems. The variable combinations defined for each class are the result of the adopted definition, the literature analysis, the visual analysis of a sample of field photographs and the analysis of the EUNIS points. The latter served as a guide for the final selection of the rules by giving more importance to the LUCAS variables combinations, resulting in a higher percentage of points belonging to classes X06 or X09. The rules in the following table are expressed in pseudo-code and can be converted into SQL language to extract the corresponding LUCAS survey points from the microdata.

Table 3 - Rules defined for the different AF classes with the number of eligible LUCAS survey points 2018.

Class	Rule_ID	Rule	No. LUCAS survey points (2018)				% in X06 OR X09
			Total	With grazing	X06	X09	
Grazed orchards (GRAZED_O)	graz_orch_r2	(LC1=B71-B77 OR B81 OR B82 OR B84k) AND (LU1=U111 OR LU2=U111) AND GRAZING=1	273	273	119	90	77%
Arable high value trees (ARABLE_T)	ara_hvt_final	(LC1=B71-B77 OR B81 OR B82 OR B84k) AND (LC2=B11-B16 OR B19 OR B21 OR B23 OR B31 OR B41-B45 OR B51-B54) AND LU1=U111	57	0	40	0	70%
Agroforestry for arable systems (ARABLE_S)	agrof_ara_r2	(LC1=C10-C33 OR D10) AND (LC2=B11-B16, B19, B21, B23, B31, B41-B45, B51-B54) AND (LU1=U111 OR LU2=U111)	75	21	66	3	92%
Agroforestry for livestock systems (LIVESTOCK_S)	agrof_liv_final	(LC1=C10-C33 OR D10) AND ((LU1=U111 AND LU2=U120) OR (LU2=U111 AND LU1=U120))	2868	2158	1503	1054	89%
Total agroforestry (removing overlaps between AF classes)			**3273**	**2452**	**1728**	**1147**	**87%**

The rules were tested for all LUCAS campaigns (2009-2018) to ensure the extraction of set of survey points without overlaps among the different classes (rules are mutually exclusive). The rule agrof_liv_final resulted in an overlap with the rule agrof_ara_r2 (73 points). Therefore, the SQL code of the rule agrof_liv_final was adjusted to remove the points extracted with agrof_ara_r2.

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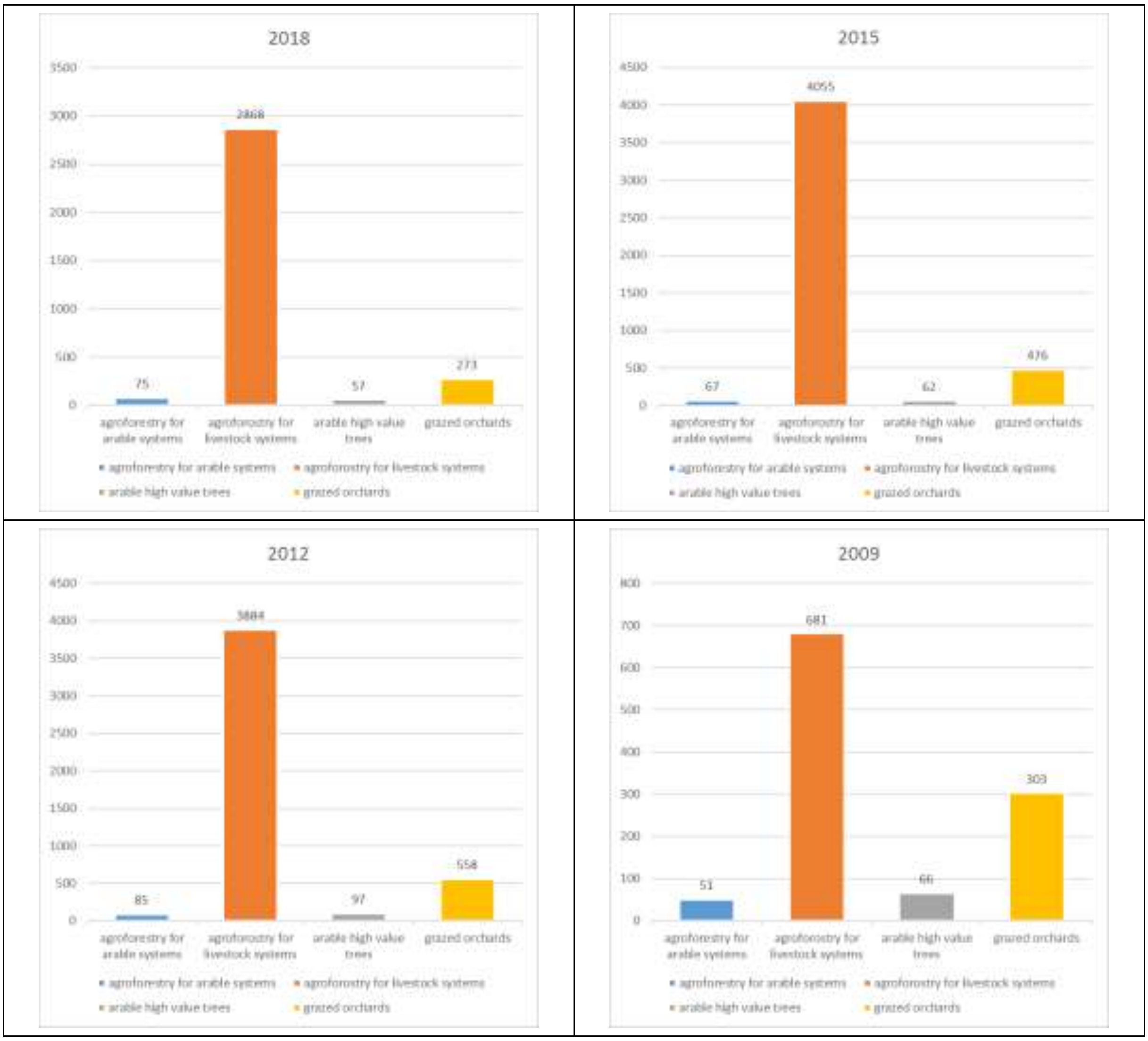
1.3 Application of the AF rules to LUCAS Surveys 2009-2018

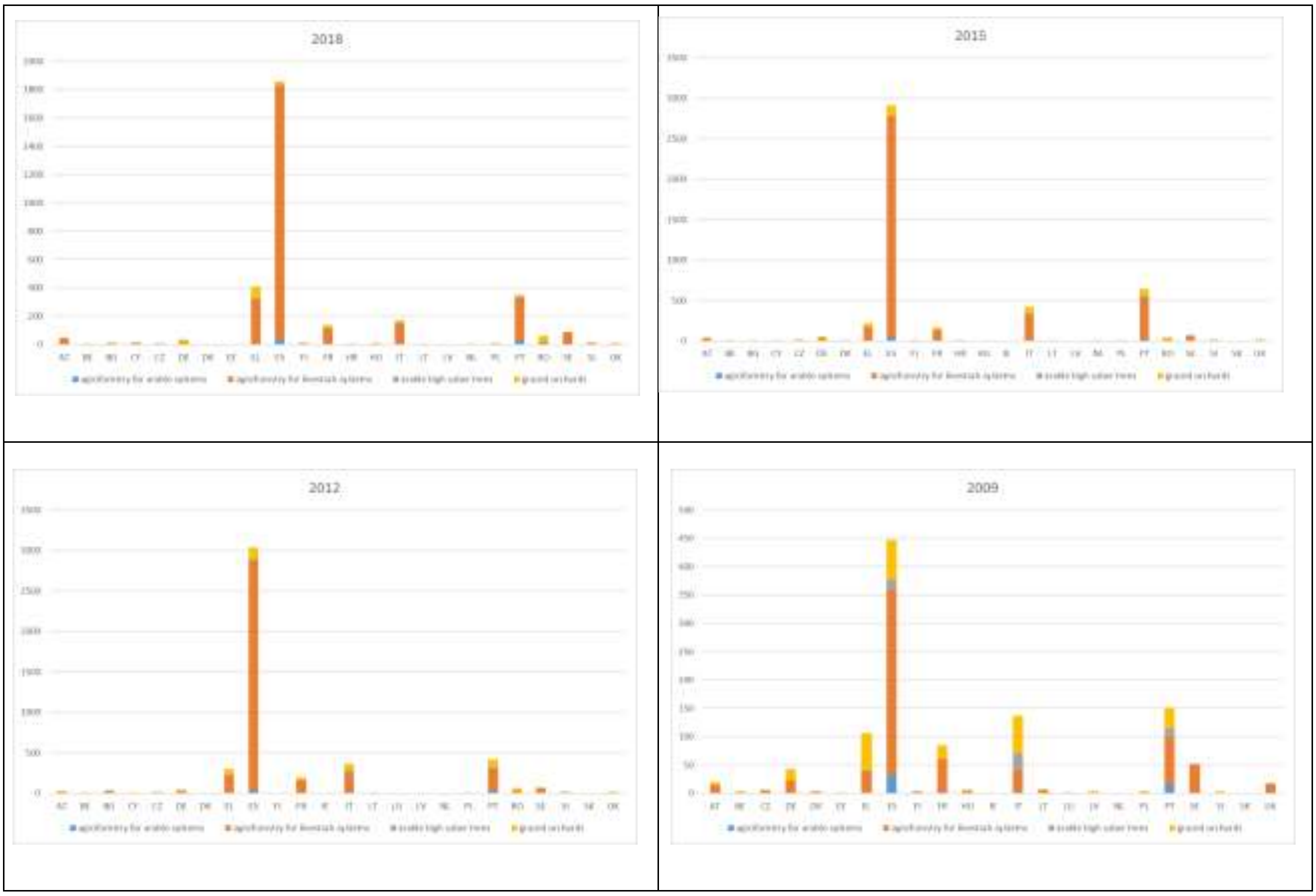
A series of graphs for each LUCAS survey year at EU and NUTS 0 level using the AF rules are presented below. In terms of the proportion of the survey sample, the AF proportion is around 1% in 2018, 2015 and 2012 and 0.4% in 2009. The number of AF points for each survey is dominated by the Agroforestry class for livestock systems, which accounted for more than 80% in 2018, 2015 and 2012 and about 62% in 2009.

Figure 8 – Number of points for each AF class for the surveys 2018, 2015, 2012 and 2009. Total number of AF points at EU-level is 3273 (2018), 4660 (2015), 4624 (2012) and 1101 (2009).



The figures by country show a clear concentration of AF points in ES with the following percentage of total AF points at EU level: 57% (2018), 62% (2015), 66% (2012), 41% (2009). In all 4 surveys, the majority of points belong to the Agroforestry class for livestock systems.

Figure 9 - Number of points for each AF class by country for the surveys 2018, 2015, 2012 and 2009.



The number of AF points and the distribution among the four classes are quite stable for the period 2012-2018, while a drastic change can be observed in 2009. This change is probably related to the evolution of the LUCAS sample between 2009 and the following campaigns. In 2009, 23 EU countries were involved (2018 and 2015: 28; 2012: 27) and LUCAS points amounted to 261610 (2018: 338854; 2015: 338725; 2012: 333916). The lower number of points in 2009 may have an effect on the number of eligible AF points at EU and country level. In particular, the total LUCAS sample in 2009 in ES counts around 38.000 points, while it increases to 45-50k points in 2015-2018.

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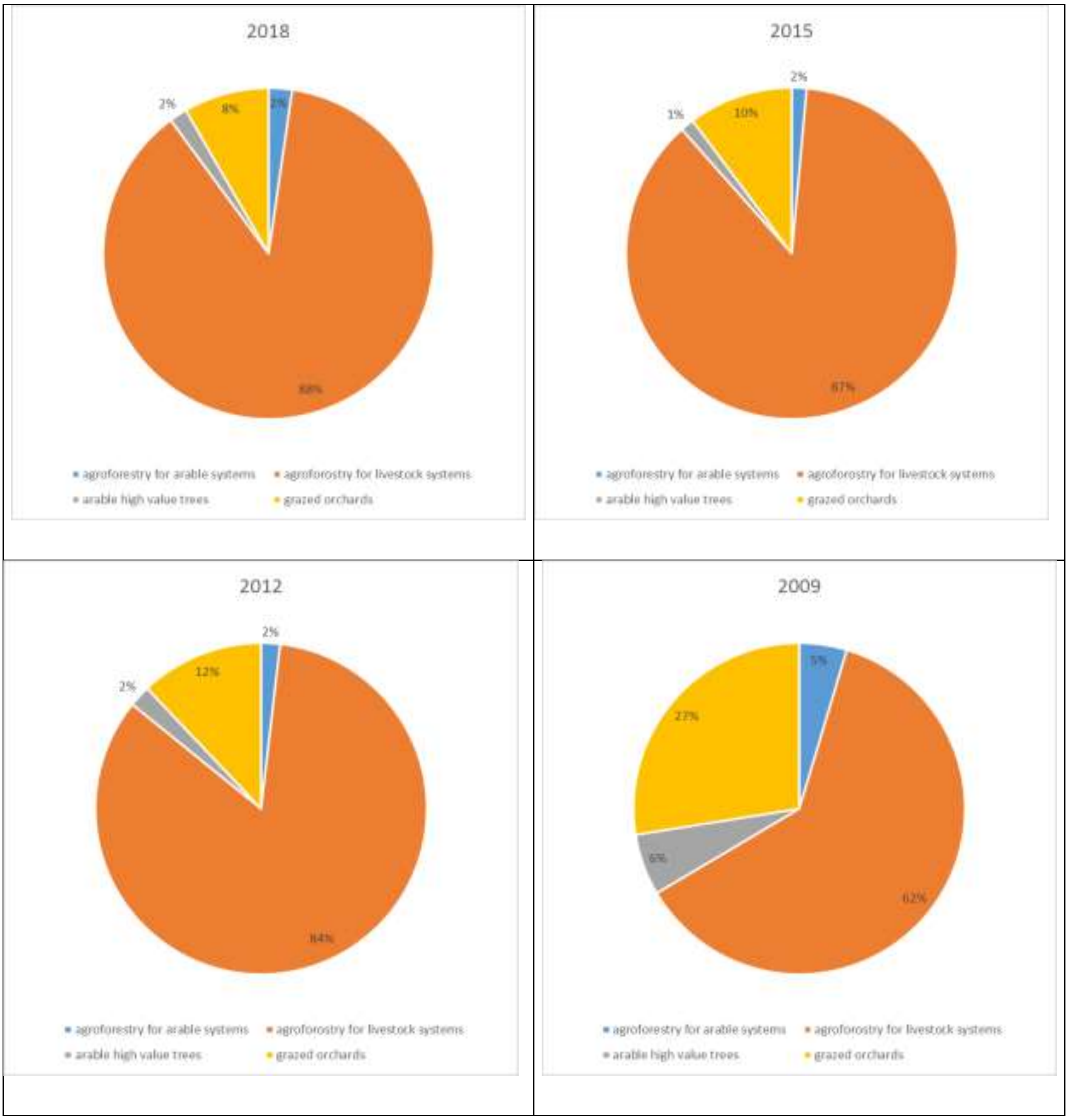
Figure 10 – Percentage of LUCAS survey points for each AF class over the total AF points by country for the surveys 2018, 2015, 2012 and 2009.



1.4 Datasets used for point extraction and in the subsequent modelling phase

The definition and application of rules for the AF classes and the subsequent modelling phase were carried out using multiple datasets, used individually or integrated. These datasets come both from the LUCAS projects and from external datasets with European coverage:

1. Harmonized multi-temporal LUCAS Surveys microdata: field points (2009, 2012, 2015 and 2018) and photo-interpreted points (2015 and 2018).
2. Datasets of photo-interpreted LUCAS points for the 2009 and 2012 LUCAS Surveys.
3. LUCAS Master Grid.
4. CORINE Land Cover 2018 and 2012.
5. Copernicus High Resolution Tree Cover Density (2012, 2015 and 2018).

Certain variables from the datasets 3, 4 and 5 were used as covariates in the modelling exercises. A complete description of the datasets 1, 2 and 3 can be found in the report for Task 2.1.

1.5 Covariates used for the modelling phase

To improve the reliability and predictive power of the models used for AF area estimation, a set of covariates related to the spatio-temporal characteristics of the AF classes were selected and used. The following table lists the covariates, their sources and provides a brief description.

Table 4 – List, source and description of the covariates used in the modelling phase.

Covariate	Source	Definition	Levels
X_LAEA	LUCAS Master Grid (Master_190517)	Longitude in meters (Lambert Azimuthal Equal Area projection -LAEA[1])	-
Y_LAEA	LUCAS Master Grid (Master_190517)	Latitude in meters (Lambert Azimuthal Equal Area projection -LAEA)	-
ELEVATION	LUCAS Master Grid (Master_190517)	Elevation in meters of the point (source EUDEM[2])	-

[1] The coordinate reference system used for pan-European statistical mapping at all scales or other purposes where true area representation is required.
[2] The Digital Elevation Model over Europe from the GMES RDA project (EU-DEM) is a Digital Surface Model (DSM) representing the first surface as illuminated by the sensors. The EU-DEM dataset is a realisation of the Copernicus programme, managed by the European Commission, DG Enterprise and Industry. Source: https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1

Covariate	Source	Definition	Levels
NUTS1_16	LUCAS Master Grid (Master_190517)	NUTS 1 from GISCO DB 2016	
NUTS2_16	LUCAS Master Grid (Master_190517)	NUTS 2 from GISCO DB 2016	
STRATUM_LABEL (STR_18)	LUCAS Master Grid (Master_190517)	Strata variable for 2018	Eight strata: 1 = Arable land 2 = Permanent crops 3 = Grass 4 = Wooded areas 5 = Shrubs 6 = Bare surface, low or rare vegetation 7 = Artificial constructions and sealed areas 8 = Inland water 9 = Transitional and coastal waters 10 = Impossible to PI
CLC_2012 and CLC_2018	CORINE Land Cover 2012 and 2018 (EEA)	Cf. CORINE Land Cover	
TCD_2012, TCD_2015 and TCD_2018	Copernicus High Resolution Layer Tree Cover Density 2012, 2015 and 2018 (Copernicus Land Monitoring Service)	Cf. Copernicus High Resolution Layers (HRLs) - Tree Cover Density (TCD)	

1.1 CORINE Land Cover

Each point of the LUCAS Master, and thus each point of the surveys, is associated with the corresponding CORINE Land Cover (CLC) class containing the point. This variable has been updated in the LUCAS Master Grid over the years by including the corresponding CLC class for the available CLC updates (2012 and 2018). The CLC reference products are available as raster maps with 100 m spatial resolution (spatial reference is the European LAEA - EPSG: 3035) projection). Due to the large update interval (6 years), a simplification was adopted: the variables from CLC18 and CLC2012 were used to cover the whole period of the LUCAS Surveys (2009-2018).

A semantic analysis of the nomenclature was carried out to identify the CLC classes that have the strongest relationship with the characteristics of the AF classes. In general, the AF classes can be linked to one or more CLC classes due to the ample definitions of the CLC nomenclature. To avoid the one-to-many relationships, only the following associations were considered.

Table 5 – Definitions of the CLC classes 244 (Agro-forestry), 231 (Pastures, meadows and other permanent grasslands under agricultural use) and 241 (Annual crops associated with permanent crops) according to the CLC

nomenclature. Source: https://land.copernicus.eu/user-corner/technical-library/corine-land-cover-nomenclature-guidelines/html/index.html

CLC class	Definition	Include	Exclude
244	Annual crops or grazing land under the wooded cover of forestry species. Mediterranean agro-forestry systems, typical of the Iberian Peninsula (named *dehesa* in Spain and *montado* in Portugal): agricultural land (arable land, pastures) shaded with forestry trees with a crown coverage of usually 10-30%. Primary use is either grazing (with cattle, sheep, goat, pigs) or arable production, which can be accompanied by harvesting of non-timber forest products such as wild game, mushrooms, honey, cork and firewood. The tree component is primarily oaks. The understorey is usually cleared every 7 to 10 years, to prevent natural succession with shrubs; Agricultural land shaded by palm trees in Mediterranean context; Areas of forest trees intermixed with fruit trees/olive trees, none of them dominating.	Arable crops or permanent grassland (pasture); in obligatory combination with trees, usually oaks, namely holm (Quercus ilex) and cork (Quercus suber), but also carob, beech, pine or palm trees; optionally shrubs.	Meadows with dispersed forest trees and shrubs occupying up to 50% of area, not under agro-forestry use (class 231 particularity: wooded meadows) arable land or pasture shaded by fruit trees or olives intermixed on the same parcel (class 241); abandoned agro-forestry areas where arable land or pasture is overgrown with shrubs (class 323 or 324). agro-forestry areas with > 30% occupancy of trees (classes 31x).
231	Permanent grassland characterized by agricultural use or strong human disturbance. Floral composition dominated by graminacea and influenced by human activity. Typically used for grazing-pastures, or mechanical harvesting of grass–meadows.	Pastures with scattered trees and shrubs, woody vegetation covering <30% of the ground; grassland areas with hedges (bocage).	Herbaceous grass cover composed of non-palatable and undesirable species for cattle such as Molinia spp. and Brachypodium spp.
241	Cultivated land parcels with non-permanent crops (mostly arable land) associated with permanent crops (fruit trees or olive trees or vines) on the same parcel.	Woody crops (fruit trees or shrubs, olives) in combination with either non-permanent crops; or permanent grass surfaces; optionally with scattered patches of greenery.	Permanent crops associated with fruit trees (classes 22x); non-permanent crops associated with forest trees in an agro-forestry system (class 244); mosaic of permanent crop and non-permanent crop parcels where none of the constituents occupy >75% (class 242); mosaic of fruit trees or vineyards or olives and non-permanent crops, where one of the permanent crops occupy > 50% (classes 22x) meadows or pastures with scattered forest trees (class 231).

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The AF class is only recorded in CLC for regions where land use is predominant. Given the generalization rules and the minimum mapping unit (25 ha), the CLC-derived statistics lead to an underestimation of the extent compared to different studies based on a literature review (den Herder, 2015 a, b). The class definition excludes AF areas with a tree density more than 30%, which should be mapped in the class (Classes 3.1 – Forests). Land features coherent with AF features can also be mapped in the Class 2.3.1 - Pastures, meadows and other permanent grassland with agricultural use, which applies to pastures with scattered trees and shrubs, woody vegetation covering <30% of the ground and grassland areas with hedges (bocage) and in general, with wooded meadows. Finally, Class 2.4.1 - Annual crops associated with permanent crops may include agroforestry features, namely arable land or pasture shaded by fruit trees or olive trees mixed on the same plot.

1.1 Copernicus High Resolution Layers (HRLs) - Tree Cover Density (TCD)

The HRL Tree Cover Density products produced in the framework of the Copernicus Land Monitoring Service were analysed to select suitable variables to be used as covariates for the whole Europe.
The TCD raster product provides information on the proportional crown coverage per pixel at 10m, 20m and 100m spatial resolution and ranges from 0% (all non-tree covered areas) to 100%. TCD is defined as “the vertical projection of tree crowns to a horizontal earth’s surface“ (see the table below for the full definition). TCD products consist of the status layers, available for the reference years 2012, 2015 and 2018, and a change product showing the increase or decrease in the tree cover mask in 2012 - 2015 and 2015 - 2018. The 100m aggregate raster is provided as a full EEA39 mosaic. The spatial reference of all products is the European LAEA (EPSG: 3035) projection.

Table 6 – Definitions of the HRL TCD. Source: https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density

Definition	Include	Exclude
TCD is defined as “vertical projection of tree crowns to a horizontal earth’s surface” and provides information on the proportional crown coverage per pixel. This information is derived from multispectral High Resolution (HR) satellite data using Very High Resolution (VHR) satellite data and/or aerial ortho-imagery as reference data. TCD is assessed on different VHR sources by visual interpretation following a 10x10 point grid approach, resulting in proportional density information on a 100m by 100m grid level.	Evergreen/deciduous broadleaved, sclerophyllous and coniferous trees of any use; Forests (grown-up and under development); Orchards, olive groves, fruit and other tree plantations, agro-forestry areas; Transitional woodland, forests in regeneration; Groups of trees within urban areas (alleys, wooded parks and gardens) Forest management/use features inside forests (forest roads, firebreaks, thinnings, forest nurseries, etc.) Forest damage features inside forests (partially burnt areas, storm damages, insect-infested damages, etc.)	Open areas within forests (roads, permanently open vegetated areas, clear cuts, fully burnt areas, other severe forest damage areas, etc.) Dwarf shrub-covered areas, such as moors and heathland Vineyards, Dwarf pine / green alder in alpine areas Mediterranean shrublands (macchia, garrigue etc.) Shrubland

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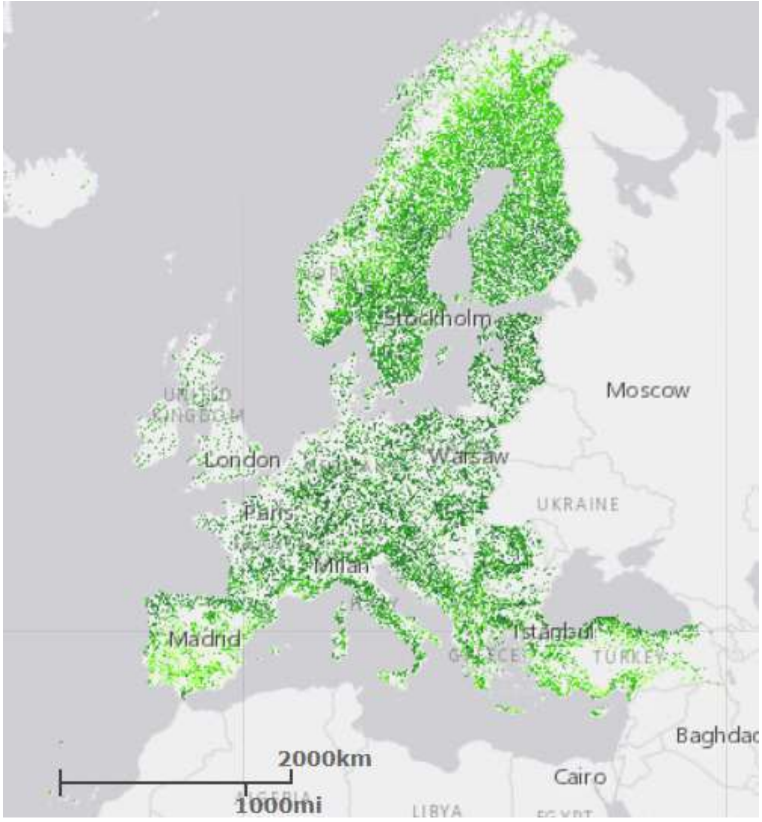
Figure 11 – The product TCD 2018 – Status Map with the full geographical coverage of the EEA 39 countries. Shades of yellow-green indicate the range 0% (all non-tree covered areas) - 100% (full coverage). Spatial resolution is 10m and the coordinate reference system is Lambert Azimuthal Equal Area Projection (LAEA).



1.6 Covariates combination

The covariates CLC and HRL can be used jointly to create an improved covariate to support the modelling process. To improve spatial localization and probability estimation based on LC/LU of LUCAS points, we integrated spatial datasets on the density of trees on agricultural land. This is consistent with some of the general definitions of AF given in the literature, namely areas where tree cover on agricultural land exceeds 10% (i.e., Zomer et al., 2009).

The combination of CLC and TCD was carried out using the data assigned to each LUCAS Master point for the different years, applying the following rules:

- 2018: TDC_18 >= 10% AND CLC18_vett = 244 OR 231 OR 241;
- 2015: TDC_15 >= 10% AND CLC18_vett = 244 OR 231 OR 241;
- 2012: TDC_12 >= 10% AND CLC12_vett = 244 OR 231 OR 241;
- 2009: TDC_12 >= 10% AND CLC12_vett = 244 OR 231 OR 241;

Where: 244 (Agro-forestry), 231 (Pastures, meadows and other permanent grasslands under agricultural use) and 241 (Annual crops associated with permanent crops).

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1.7 Comparison with other data sources

There are very few sources that provide data on the areal extent of AF classes in Europe. We identified two reference sources that report the areal extent of a general AF class that can be compared with the model-based area estimates carried out in this work. However, it must be emphasized that the definitions for the AF classes are generally not fully comparable with the definition used here. In addition, the sources given in the literature are quite variable (administrative data, statistical data, etc.) and may refer to different years.

Table 7 – Reference sources reporting AF area figures at NUTS 0 identified to perform a comparison with the model-based area estimation.

ID	Source	Notes
a	den Herder, M., Burgess, P.J., Mosquera-Losada, M.R., Herzog, F., Hartel, T., Upson, M., Viholainen, I., Rosati, A., 2015a. Preliminary stratification and quantification of agroforestry in Europe. Milestone Report 1.1 for EU FP7 AGFORWARD Research Project (613520). Available online at: http://agforward.eu/index.php/en/preliminary-stratification-and-quantification-of-agroforestry-in-europe.html 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., 2015b. 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-ofagroforestry-in-the-eu27.html	Statistical data from original country datasets at different administrative level (e.g., statistical data, forestry inventories, administrative data from IACS, LU/LC maps). Data are referred to different years depending on the country and on the specific AF class. The time range is 2001-2013.
b	den Herder, M., Moreno, G., Mosquera-Lozado, R. M., Palma, J. H., Sidiropoulou, A., Freijanes, J. J. S., ... & Burgess, P. J. (2017). Current extent and stratification of agroforestry in the European Union. Agriculture, Ecosystems & Environment, 241, 121-132.	The estimations were carried out based on the 2012 LUCAS survey. The area calculation is based on the area weight assigned to each survey point, the grid size of the LUCAS Master: 4 km^2.

Table 8 – Area estimation (x 1000 ha) for the general class AF according to the sources and b.

NUTS 0	AF (Source a)	AF (Source b)
AT	48.6	160.8
BE	12.4	43.7
BG	869.9	870
HR	64.5	-
CY	47.5	47.5

NUTS 0	AF (Source a)	AF (Source b)
CZ	9.2	45.8
DK	3.2	16.2
EE	14.4	14.4
FI	7.3	158.1
FR	510.1	1562.2
DE	480.5	263.5
EL	2096.7	1616.4
HU	22.8	38.1
IE	224.4	224.4
IT	967	1403.9
LV	23.4	23.4
LT	38.6	38.6
LU	7.2	7.2
MT	0.4	0.4
NL	3	27.8
PL	200	100.4
PT	1842.3	1168.3
RO	180.1	888.2
SK	92	43.9
SI	185	56.3
ES	3839.9	5584.4
SE	100	465.5

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2 Agroforestry land cover area estimations

2.1 Introduction

In the following, the methods, the underlying data and the validation and comparison steps are presented with regard to the estimation of land cover area for different classes of agroforestry in the EU. The different variables or classes considered (as defined in Chapter 1.2) are:

- GRAZED_O = grazed orchards;
- ARABLE_T = arable high value trees;
- ARABLE_S = agroforestry for arable systems;
- LIVESTOCK_S = agroforestry for livestock systems.

In addition, e.g. for comparison with external data, all four classes were combined into a single class AGROFORESTRY. The statistical methodology is closely related to the methods in Task 2.1. and 2.2. respectively. Thus, in the following we only present the methodological differences to the methods in 2.1/2.2, and refer more to the report on Task 2.1. for further technical details. For the definition of AF classes, we refer to the previous sections.

2.2 Statistical methods

The regression approach used to estimate land cover area is very similar to the approach presented in Task 2.1. The only differences are in the potential covariates examined: similar variables were examined (spatial coordinates, elevation, NUTS1 and NUTS2 levels, a stratum-related variable, as well as a variable based on the Corine Land Cover (CLC) dataset, and a second variable generated from the Copernicus high resolution layer (HRL)), but the detailed variables extracted from CLC and HRL were different: levels 244, 231 and 241 were used from CLC, whereas a tree cover density (TCD) was extracted from HRL. Both were considered as main effects and interaction terms, and two variants of each variable were tested: for CLC, a binary variable (either belonging to the three classes mentioned above or not) and a variable with 4 levels (one level for each class plus one additional level for ”not belonging to any of these classes”). For TCD, continuous tree cover density and a binary variable based on a threshold of 10 % were used.

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2.2.1 Visual validation

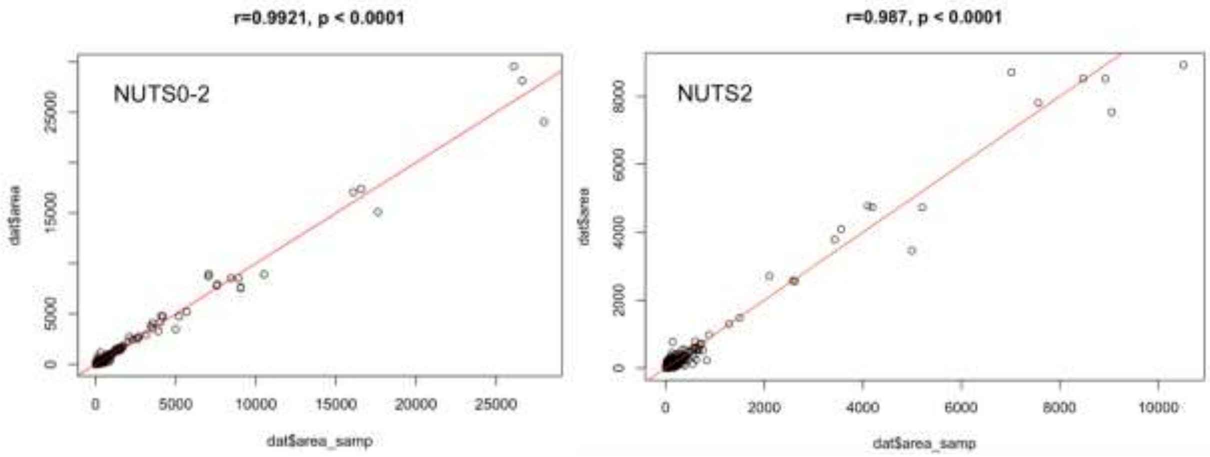
To validate the regression-based land cover area estimates for agroforestry, we spatially plotted the predicted probabilities along with the underlying LUCAS in situ point data (separately for each country and each combination of agroforestry levels) in order to validate separately for each country if the model-based patterns reasonably reproduce the patterns observed in the underlying point data. No obvious deviations were detected. These plots are given in deliverables D.2.3.1. In addition, we plotted (again separately for each country and fallow land type) the point estimates for the area estimations along with the estimated confidence intervals, as well as the area estimates from design-based (model-assisted) approaches for additional visual validation. Again, no issues were identified and deliverables D.2.3.1 also include these plots.

2.2.2 Validation/comparison with design-based (model-assisted) estimates

An important step is the comparison between model-based and design-based estimates. The weights for the latter were previously calculated for each point in each LUCAS survey and provided to us by the other statistical expert in this project. In particular, the previous approach was a model-assisted approach, as the calibrated weights were calculated from the initial weights (inverse of the probabilities of inclusion assigned to each point in the Master), taking into account some important parameters in the population (as the total areas, the elevation classes and HRL and CORINE Land Cover classes) using machine learning techniques.

Figure 17 shows a comparison of the model-based and design-based (model-assisted) land cover area estimates where the x-axis represents the design-based estimates (including only areas where LUCAS in situ data exist), and the y-axis represents the model-based estimates. The plot on the left-hand side is based on the NUTS0-NUTS3-levels in the EU for all four years/surveys considered combined, the plot on the right-hand side is based on the NUTS2 level only. It can be seen that both measures are strikingly correlated, there is not a single strong outlier. The correlation between the two approaches is very high with $r = 0.992$ (respectively $r = 0.987$) and $p < 2.2e\ 16$. This suggests that for the subareas for which LUCAS points (and thus design-based estimates) are available, the point estimates from both methods perform equally well. However, there might be differences in variance estimates between the two methods (e.g., because the model-based estimates might cope better with spatial autocorrelation), which we did not systematically evaluate.

Figure 12 Comparison of model-based vs. design-based (model-assisted) land cover area estimates for agroforestry. X-axis: design-based estimates, Y-axis: model-based estimates. The plot on the left-hand side is based on all existing NUTS0-NUTS2-levels and all considered years (2009, 2012, 2015, 2018) in the EU, the plot on the right-hand side based on the NUTS2 level only.



2.2.3 Validation/comparison with external data sets.

Finally, we also compared our model-based land cover area estimates for agroforestry with area estimates obtained from the external sources [1, 2]. The comparison on the NUTS0-level is in Tab. 1. Again, it can be seen that our model-based estimates correlate very well with these external estimates, however, in average, model-based estimates appear to be slightly higher. This can most likely be explained by the different agroforestry definitions. External sources can adopt broader or narrower definitions of classes and subclasses of AF than our definition. In addition, external sources may use administrative and statistical data collected for reference periods that do not align with the years of our estimations. The only noticeable difference to the external estimates is seen in Spain: while the magnitudes of the external estimates and the model-based estimate are similar for 2009, there is an approximately 5-fold increase in the model-based estimates for the following three studies. We also observe this sudden increase from 2009 onwards in the relative number of underlying LUCAS points in Spain classified as agroforestry, which is due to changes in the LUCAS sampling design.

2.3 Results

The final land cover areas were separately estimated for the years 2009, 2012, 2015 and 2018. In addition, where possible, they were also evaluated separately for the four levels.

GRAZED_O = grazed orchards,

ARABLE_T = arable high value trees,

ARABLE_S = agroforestry for arable systems, and

LIVESTOCK_S = agroforestry for livestock systems.

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Similar to Task 2.1 and 2.2, results are given in two ways:

6 by a summary data frame comprising model-based land cover area estimates along with several measures of uncertainties (such as 95 % confidence limits as well as COV) and the design-based (model-assisted) area estimates for comparison for each NUTS0, NUTS1, NUTS2, and NUTS3 level; these results are provided in deliverables D.2.3.2;

7 by the Master data frame where the model-based probabilities for the different fallow land classes (if available) are attached to each Master pixel. These results are provided in deliverables D.2.3.3.

The model-based estimated probabilities of different agroforestry types are shown in Fig. 2–6. Numerical data on land cover area estimates are in Tab. 1 (last four columns). Bar plots of the land cover area estimates at NUTS0 level (together with certainty estimates) are shown in Fig. 7

Land cover area estimates at NUTS1-levels are presented by way of example for the most frequently occurring.

Table 9 – Comparison of external estimates for agroforestry from ”source_a” (Ref. [1]) and ”source_b” (Ref. [2]) with our model based estimates for the different years (last 4 columns). For the latter, the estimates of all 4 considered agroforestry classes have been summed up.

country code	country	source_a	source_b	2009	2012	2015	2018
AT	Austria	49	161	231	302	421	505
BE	Belgium	12	44	54	59	40	52
CZ	Czech	9	46	94	179	180	126
DE	Germany	480	264	709	603	750	497
DK	Denmark	3	16	51	19	25	46
EE	Estonia	14	14	35	0	0	68
EL	Greece	2097	1616	1389	3167	2270	4369
ES	Spain	3840	5584	5841	30370	31512	24922
FI	Finland	7	158	54	23	78	267
FR	France	510	1562	1308	2127	1916	1852
HU	Hungary	23	38	102	0	34	164
IE	Ireland	224	224	17	55	35	0
IT	Italy	967	1404	1950	4080	4762	1704

country code	country	source_a	source_b	2009	2012	2015	2018
LT	Lithuania	39	39	118	85	55	57
LU	Luxembourg	7	7	35	32	0	0
LV	Latvia	23	23	50	24	36	11
NL	Netherlands	3	28	15	24	67	36
PL	Poland	200	100	50	122	95	116
PT	Portugal	1842	1168	2483	4178	6354	3506
SE	Sweden	100	466	880	1148	964	990
SI	Slovenia	185	56	55	113	117	154
SK	Slovakia	92	44	25	44	52	0

Agro-forestry class (LIVESTOCK_S) and four countries (EL, ES, IT, PT) in Fig. 8-9, together with certainty estimates (coefficient of variation).

Since the land cover area estimates of different agroforestry classes (in particular, the three classes ARABLE_T, ARABLE_S, but also GRATZED_O) are often associated high uncertainties, their interpretation must be made with caution. In particular, in several cases – even at the NUTS0 level – the corresponding coefficients of variation are highly inflated. Therefore, if land cover area estimates for a particular agroforestry class and region (e.g., NUTS-ID) are of particular interest, the following points should be carefully considered:

1. How large are the associated 95 % confidence intervals? (c.f., Fig. 7 above for NUTS0 and selected countries);
2. How large is the associated coefficient of variation? (c.f., Fig. 7 below or NUTS0 and selected countries));
3. Are the observed spatial patterns across the four surveys comparable? (c.f., Fig. 2-6).

Regarding the last point, spatial patterns can change in reality. However, the actual size of the land cover area and the distribution of agroforestry between two surveys should change only moderately (if at all) on the visible scale, as it is assumed to change rather slowly over time [1, 2].

Strong fluctuations in predicted spatial patterns between successive surveys are therefore more likely to be the result of model uncertainties, again based on sparse data, and possibly interacting with changes in the LC/LU assessment of points in different LUCAS campaigns. Taking ARABLE_S (agroforestry for arable systems) as an example, we can conclude from Fig. 3 that there is a hotspot for this type of agroforestry in the Southeast of the Iberian Peninsula, as all 4 plots indicate this. However, as the underlying data are sparse (which can also be seen from the very low model-based probabilities), the detailed small-scale spatial patterns fluctuate between the surveys and should thus not be overinterpreted. A similar situation exists in Italy, where the patterns in all four

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surveys indicate a higher concentration of ARABLE_S in the South, but the small-scale patterns differ greatly between surveys and are therefore less reliable.

Figure 13 - - Model-based estimated probabilities of agroforestry (all 4 levels summed up) for 2009, 2012, 2015 and 2018. Administrative boundaries: c EuroGeographics c UN-FAO c Turkstat, Cartography: Eurostat - GISCO

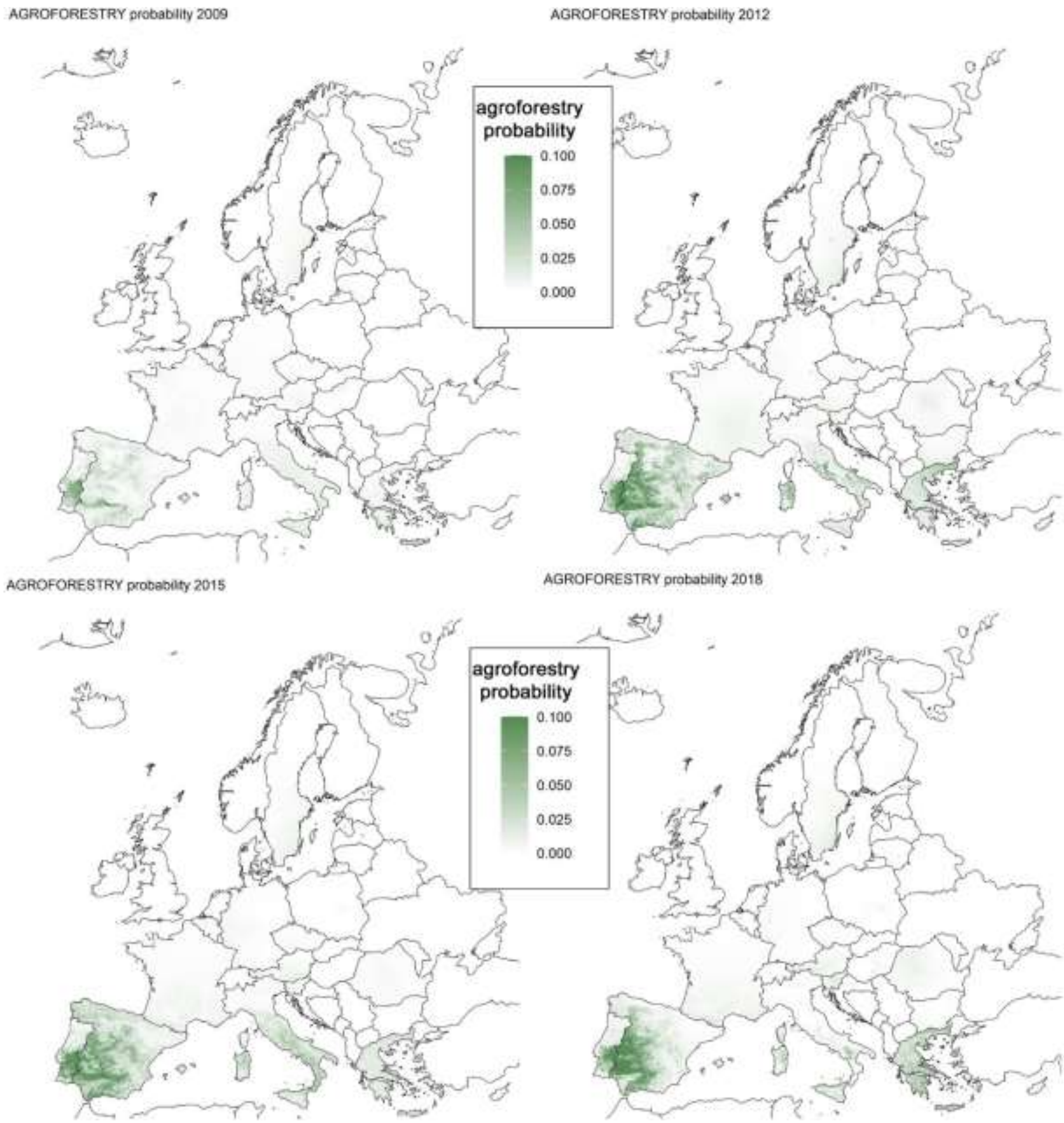

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Figure 14 - Model-based estimated probabilities of ARABLE_S (agroforestry for arable systems) for 2009, 2012, 2015 and 2018. Administrative boundaries: c EuroGeographics c UN-FAO c Turkstat, Cartography: Eurostat – GISCO

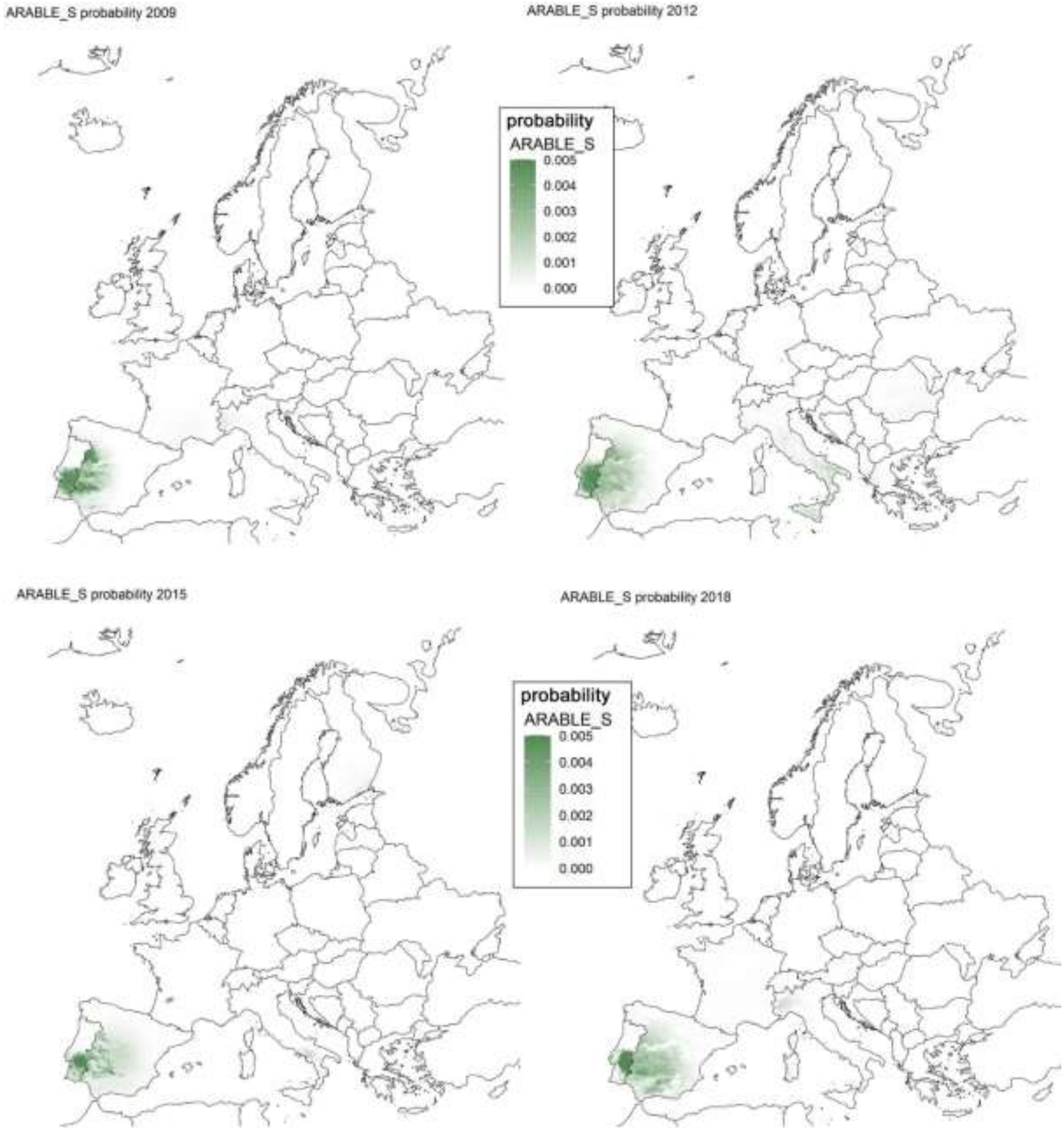

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Figure 15 - Model-based estimated probabilities of ARABLE_T (arable high value trees) for 2009, 2012, 2015 and 2018. Administrative boundaries: c EuroGeographics c UN-FAO c Turkstat, Cartography: Eurostat - GISCO.

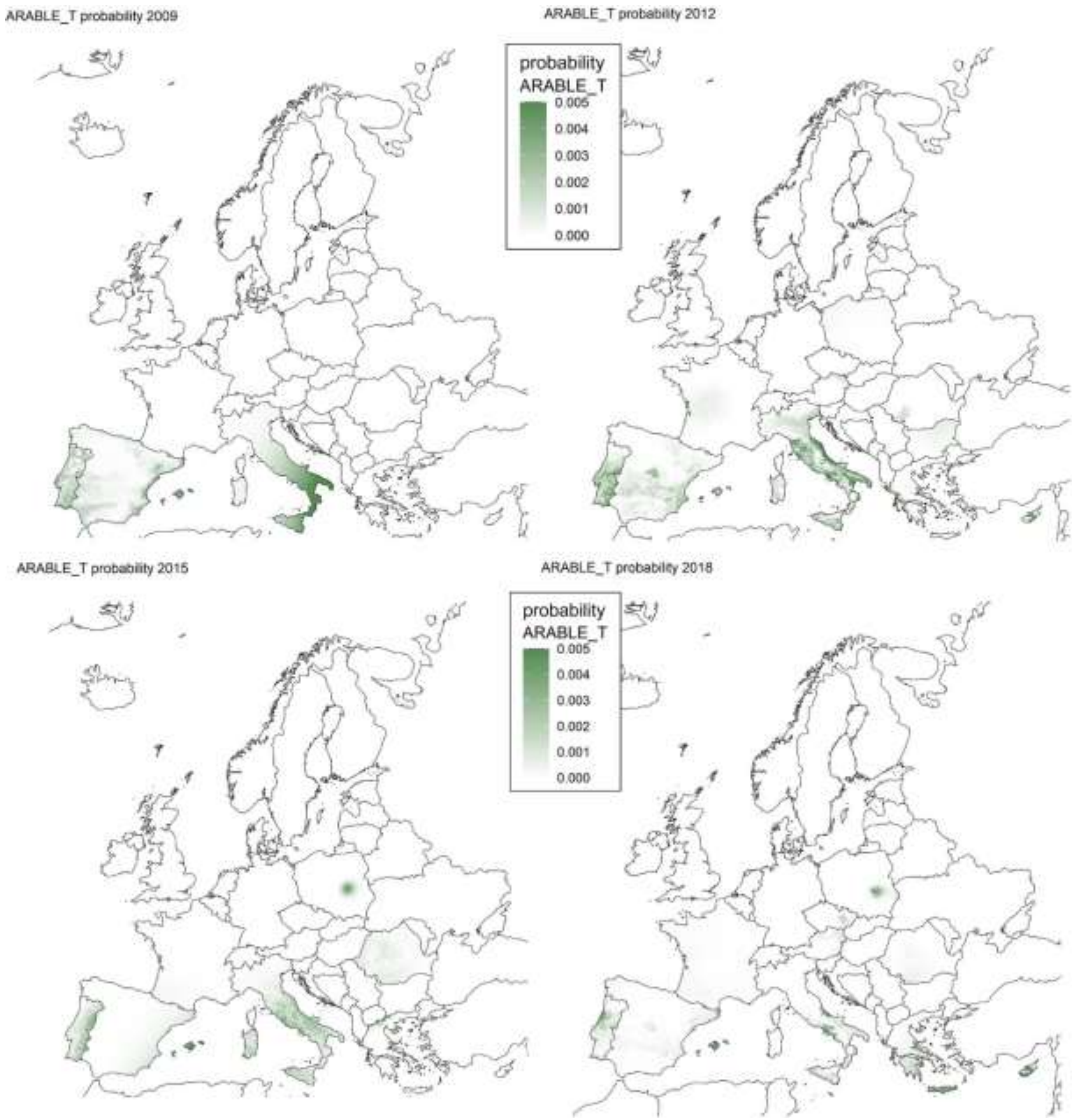

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Figure 16 - Model-based estimated probabilities of GRAZED_O (grazed orchards) for 2009, 2012, 2015 and 2018. Administrative boundaries: c EuroGeographics c UN-FAO c Turkstat, Cartography: Eurostat

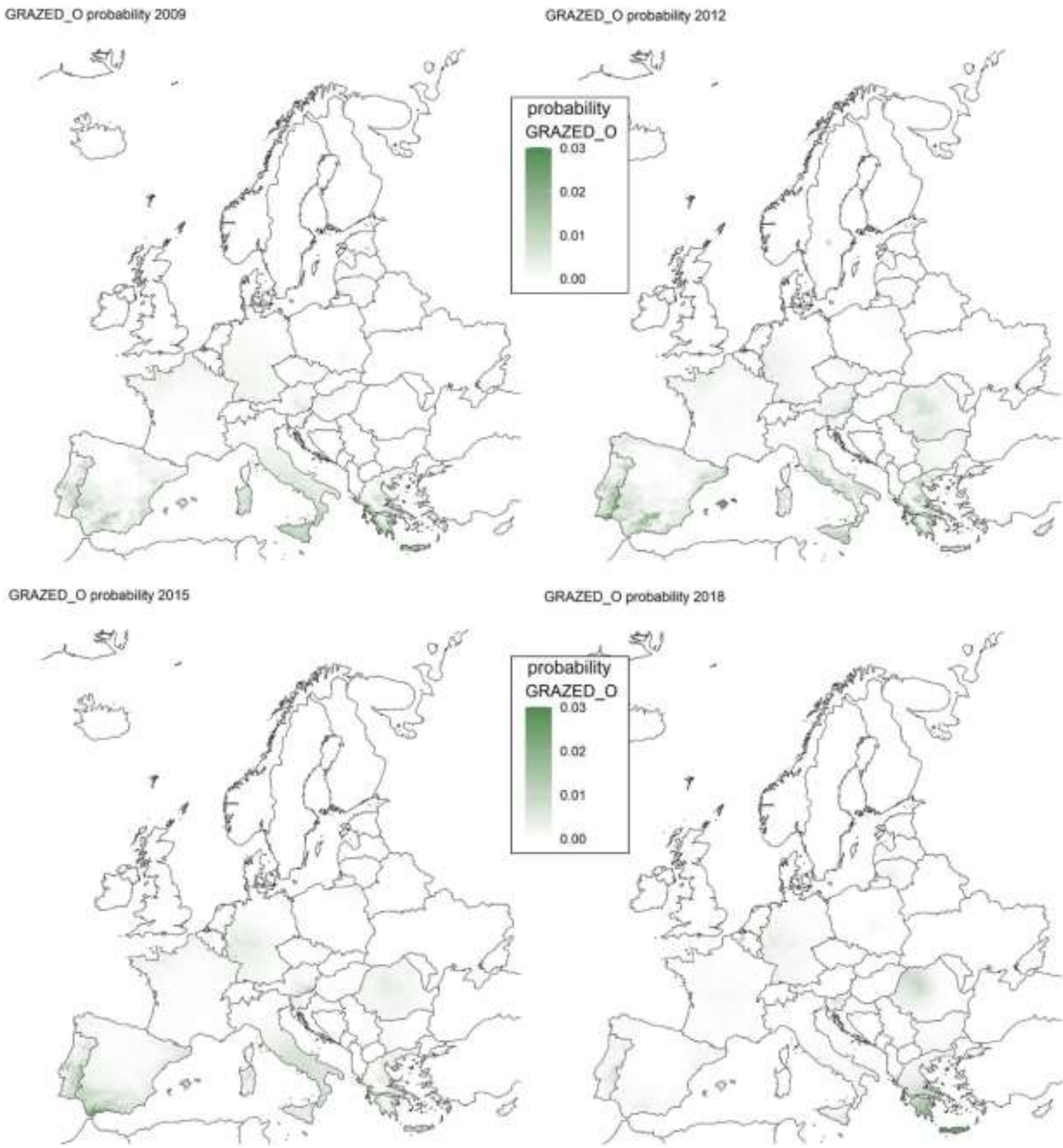

Figure 17 - Model-based estimated probabilities of LIVESTOCK_S (agroforestry for livestock systems) for 2009, 2012, 2015 and 2018. Administrative boundaries: c EuroGeographics c UN-FAO c Turkstat, Cartography: Eurostat - GISCO.

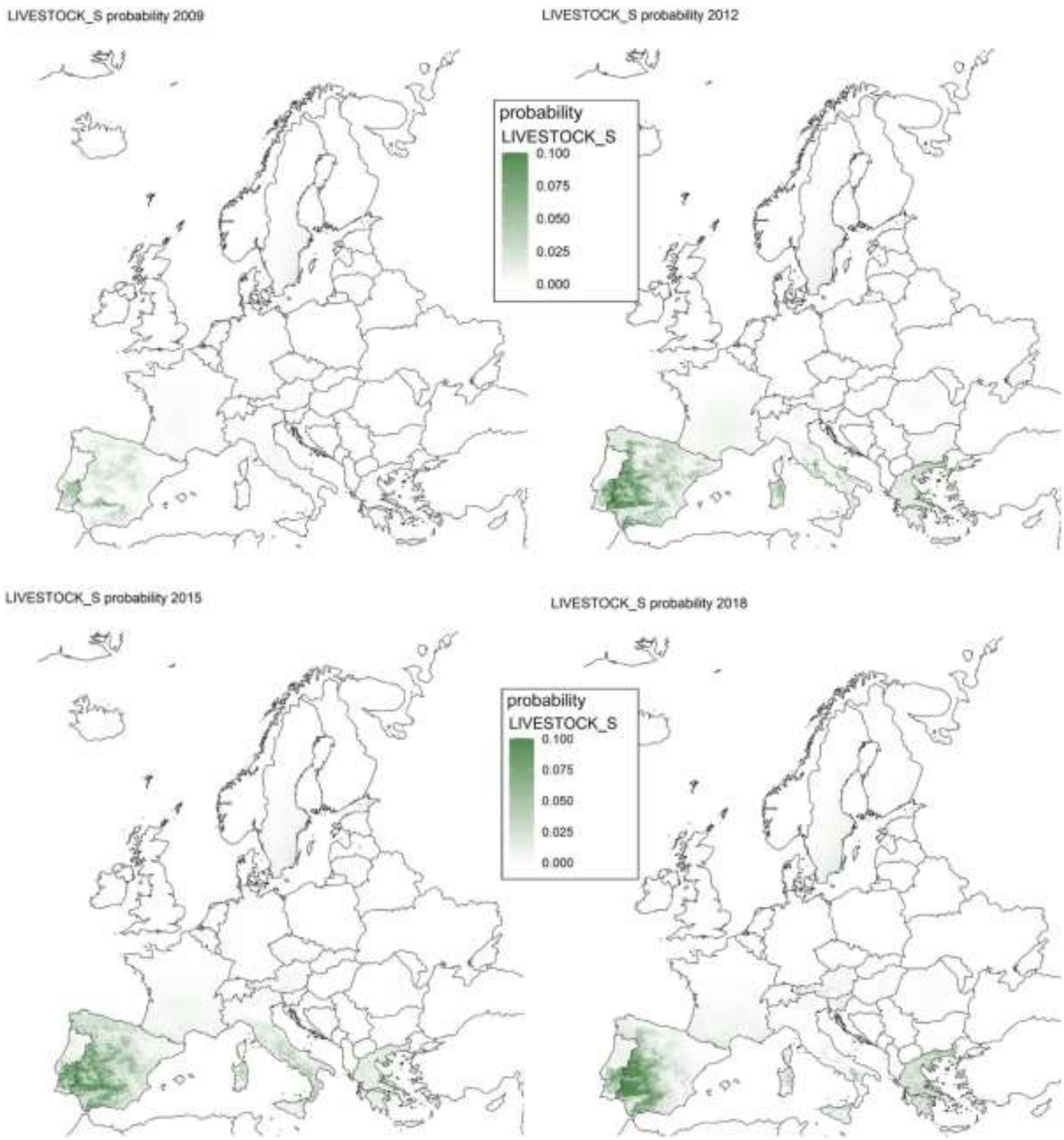

Figure 18 - Model-based estimated land cover area estimates (bars - in km2) per country for the different agroforestry classes and years. In the four upper plots, only lower 95 % confidence limits are shown (whiskers) and the colour represents the year. In the lower four plots, the colour of the bars represents the logarithm of the coefficient of variation ("COV2"). The lower the value (greenish colours), the more certain the estimate.

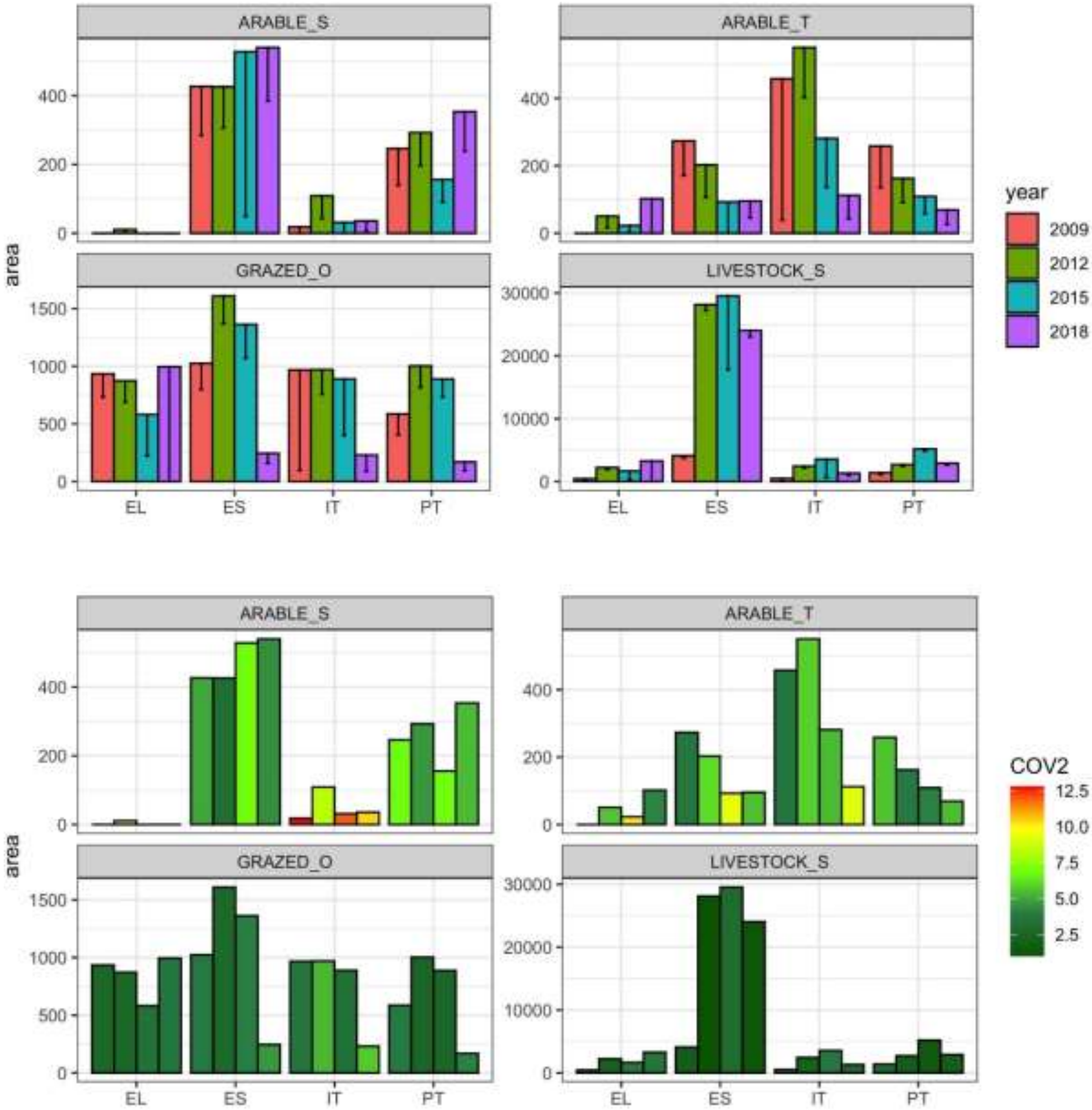

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Figure 19 - Model-based estimated of LIVESTOCK_S (agroforestry for livestock systems) for 2009 and 2012. Plots with green/yellow/red-scale: land cover area (km2), plots with blue-scale: coefficient of variation (COV) given in percentage. The figure is restricted to the values from four countries (EL, ES, IT, PT) only. Administrative boundaries: c EuroGeographics c UN-FAO c Turkstat, Cartography: Eurostat - GISCO.

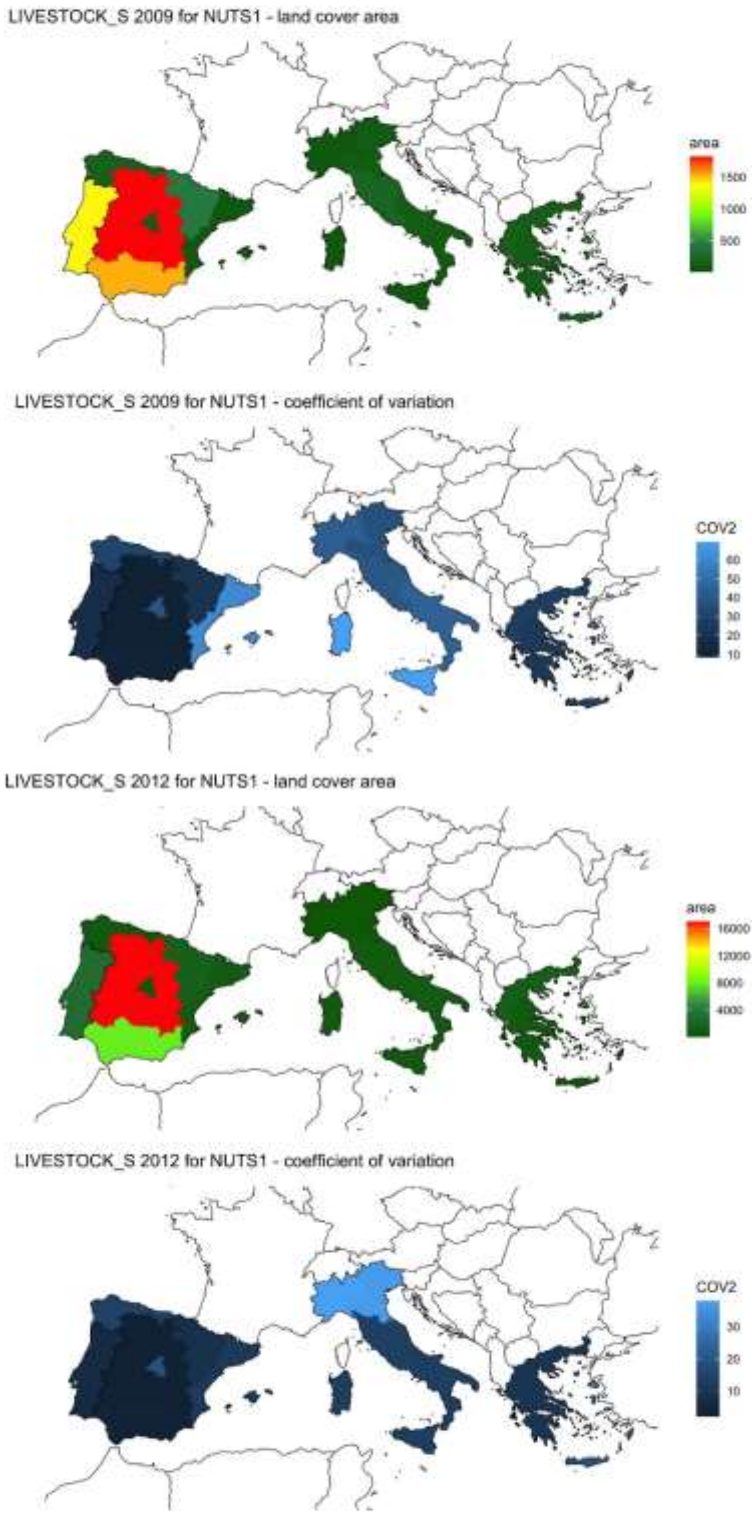

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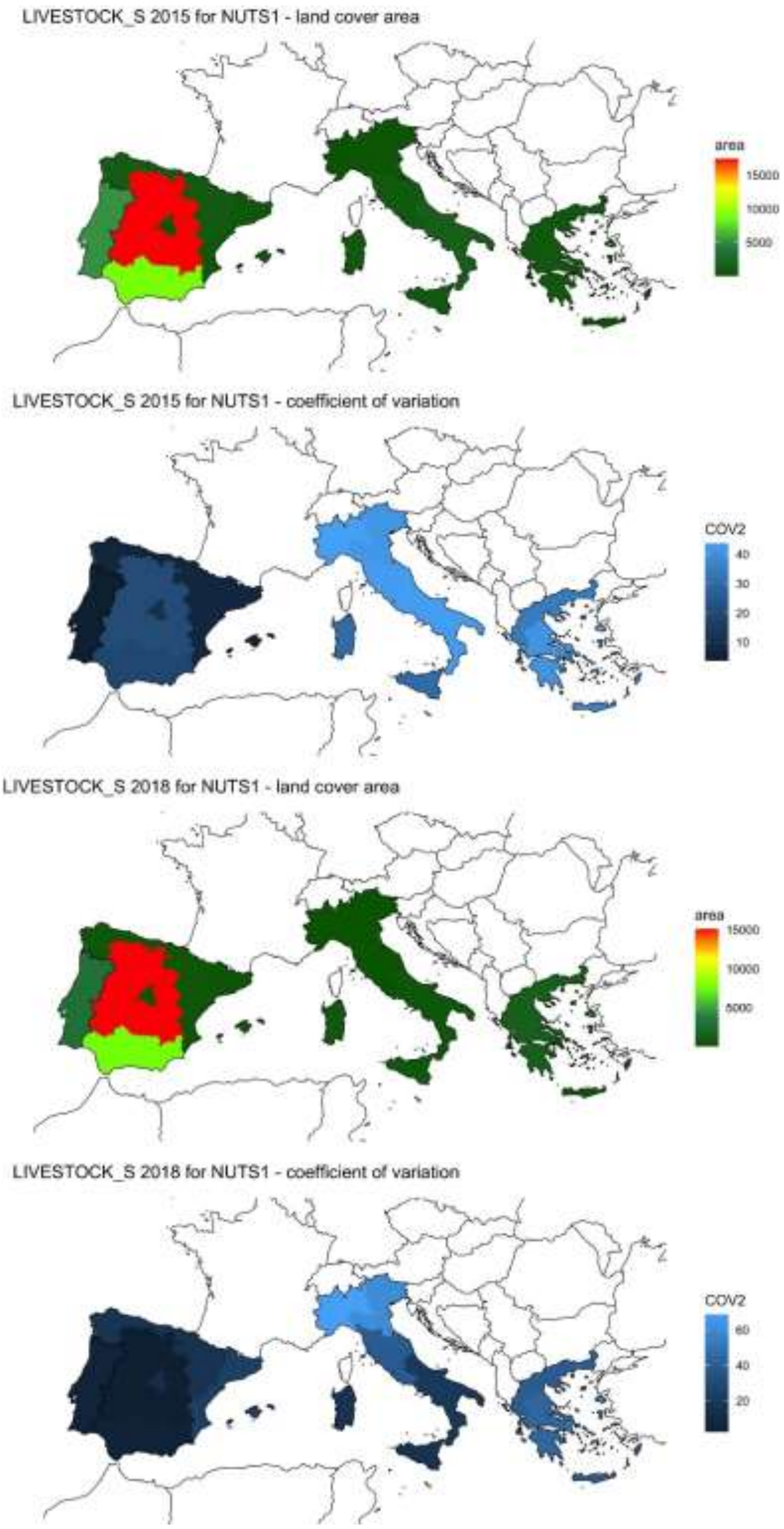
Figure 20 - Model-based estimates of LIVESTOCK_S (agroforestry for livestock systems) for 2015 and 2018. Plots with green/yellow/red-scale: land cover area (km2), plots with blue-scale: coefficient of variation (COV2) given in percentage. The figure is restricted to the values from four countries (EL, ES, IT, PT) only. Administrative boundaries: c EuroGeographics c UN-FAO c Turkstat, Cartography: Eurostat - GISCO.



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