MIXED
EFFICIENT AND RESILIENT
MIXED FARMING & AGROFORESTRY

MIXED

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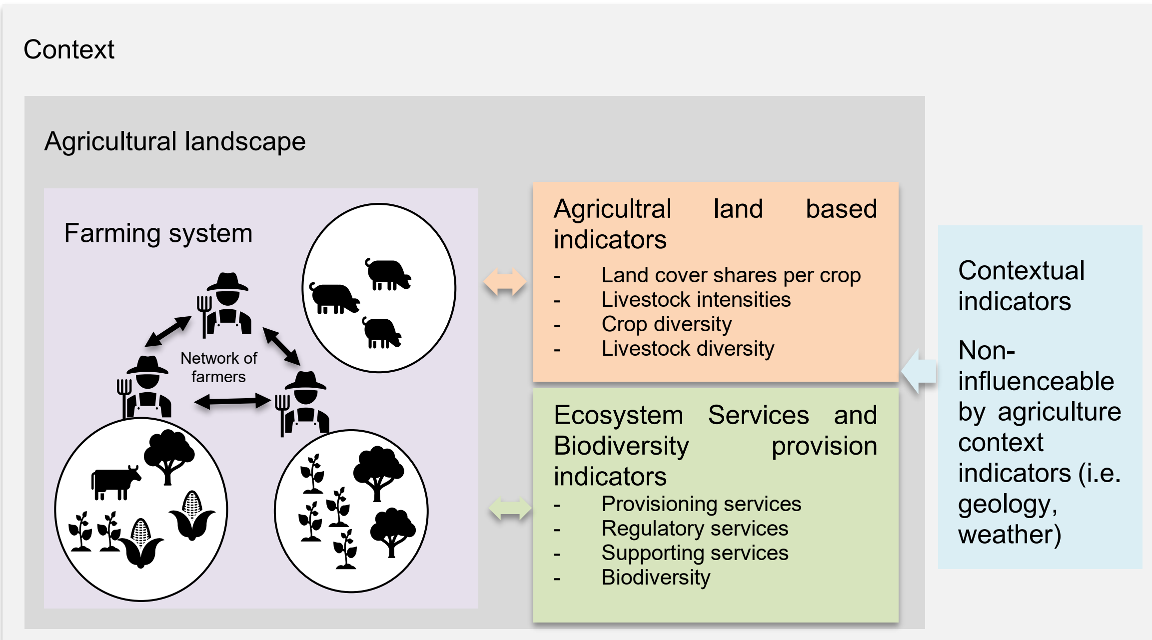
Executive Summary

Introduction

The MIXED project hypothesises that mixed farming (e.g., crop-livestock or agroforestry systems) optimizes efficiency and resource use, reduces GHG emissions, and shows greater resilience to climate change. Mixed farming plays out at different levels and can impact landscapes and regions. At the landscape level, because of the complex interaction between individual farms within a specific context, these impacts are not the mere sum of impacts measured at farm level. This is a scaling problem, which can be assessed from two perspectives, a bottom-up and a top-down approach, the core topic addressed in work package 3. This deliverable focuses on the top-down approach, exploring regional patterns mixed farming across Europe based on land-use and information aggregated at the landscape scale and identifying areas for expansion.

Conceptual framework

This deliverable develops a conceptual framework to define mixed farming systems at landscape level based on principles of landscape ecology. In this perspective, 'landscape' is understood as a heterogeneous land area comprising a mosaic of interacting ecosystems which are repeated in similar forms. For the purposes of this project and to align with the available data, we used the second level of administrative boundaries as a definition of a landscape, also known as NUTS2 boundaries (Nomenclature of Territorial Units for Statistics, Level 2). This conceptual framework considers that a network of farmers that provides a specific combination of crop and livestock activities takes place within a location where agricultural activities co-create the landscape yet are bounded by a context, these are constraining factors such as climate or geology that cannot be influenced by agriculture.

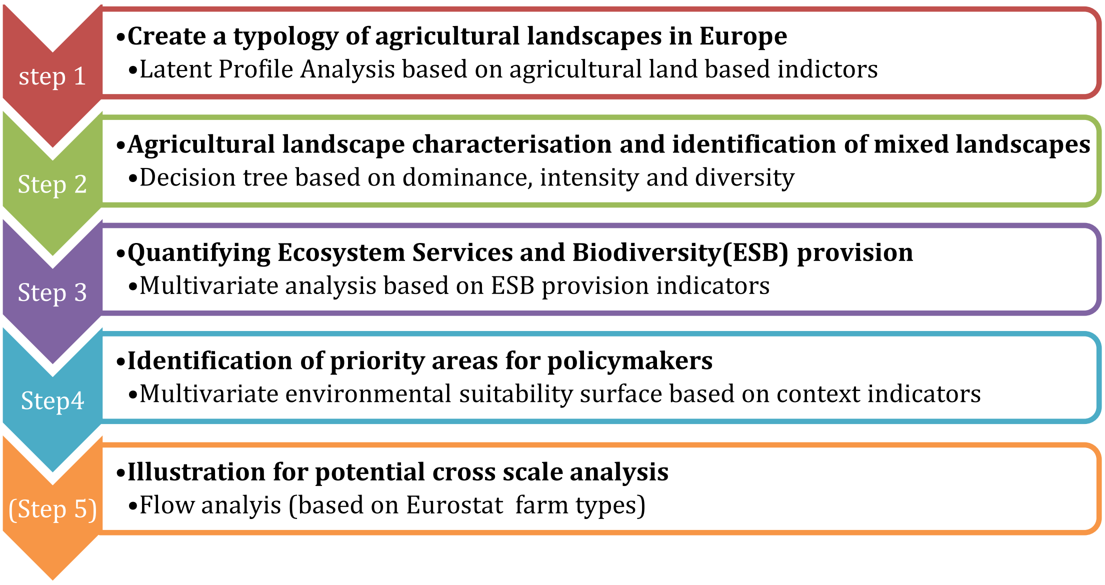


Based on this conceptual framework, we defined the following research objectives:

1. *Classify all European landscapes (defined as the second level of administrative boundaries) into different classes of combinations of agricultural activities observed at the landscape level.*
2. *Identify landscape classes that can be considered "mixed agricultural landscapes".*
3. *Explore the relationship between agricultural ecosystem services, biodiversity provision, and mixed agricultural landscapes.*
4. *Identify which non-mixed agricultural landscapes can be found in similar contexts to the mixed ones.*
5. *Explore which farm types lead to the emergence of a mixed agricultural landscape*

Material and methods

An interdisciplinary multi-step approach was defined to address the five research objectives, each step answering one of the research questions using the most appropriate method from different disciplines.

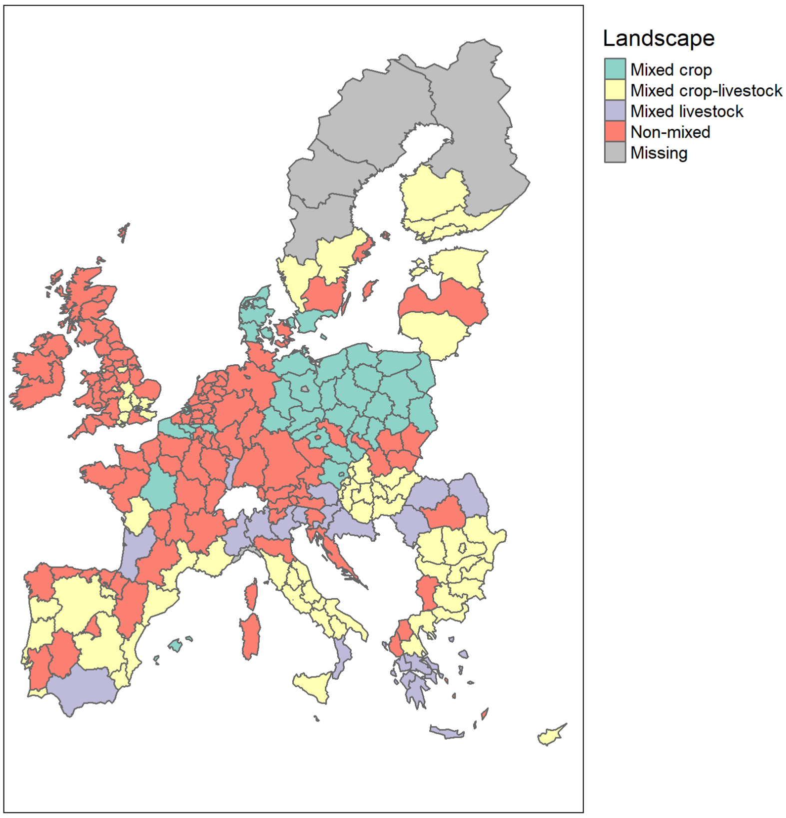


*To implement these different methods, two databases were built. The first database, containing agricultural land-based indicators and ecosystem services and biodiversity indicators at NUTS2 level was built to address steps 1,2, 3, and 5. Agricultural land-based indicators as well as farm types were derived from the Eurostat database (*https://ec.europa.eu/eurostat/web/main/data/database*). Ecosystem services indicators were derived from Eurostat but also computed from high-resolution satellite-derived maps, namely the 2018 eurocrop map from JRC (d'Andrimont et al., 2021) and the small woody feature map from Copernicus (Copernicus Land Monitoring Service, 2019). To address step 4, a geographical database was built with a whole range of publicly available data on climate, elevation, soil, and travelling time data*.

Results

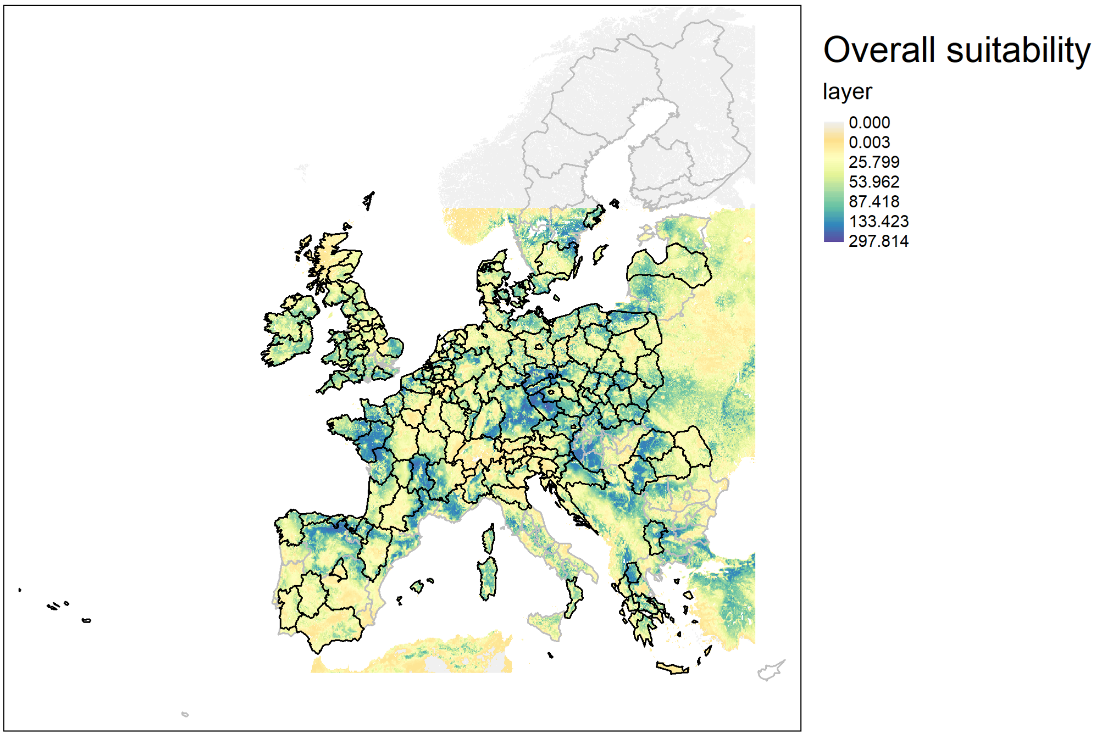
Each step leads to a specific result, namely

1. *Europe can be divided into 19 classes of landscapes that have a similar combination of agricultural activities. Each of these classes is characterised and described separately in the deliverable.*
2. *In Europe, six landscape classes, about 20% of the European landscapes, can be considered "mixed crop-livestock", these are mainly found in marginal areas, in the Mediterranean, Scandinavia and selected eastern European countries.*



3. *No clear pattern could be found between mixed landscapes and ecosystem service provision. There are trade-offs between soil formation and spatial crop diversity and between a good level of circularity of the nutrient cycle with a high food and fibre provision.*

4. *Results show that not all areas are equally suitable for becoming more mixed. More particularly, areas with a high share of permanent grassland have only a few options to become more mixed.*



5. *Results show that mixed agricultural landscapes can emerge from both farm networks of mixed farms and farm networks of specialised yet diverse farms.*

Discussion and conclusion

This study classified MIXED landscape based on areas with similar combination of activities identified through latent class. The hypothesis behind this approach is that these area with similar combinations of activities can be compared to each other. The downside of this approach is that these areas are huge and the local variability is not considered in the proposed classification. Future work should explore alternative decision rule at landscape level rather than areas with similar combination of activities.

The fact that no pattern between mixed landscapes and agricultural ecosystem services and biodiversity provision could be found, does not per se mean that mixed landscapes are not increasing the agricultural ecosystem services and biodiversity provision. This result could be linked to the choice of the metrics on biodiversity, namely the density on crop field edges, heterogeneity of annual crops and the density of small woody features. While these three variables are good proxy for biodiversity in landscapes shaped by annual crops, they are more problematic in a pan-European context in which more diverse agricultural landscape are found, such as Mediterranean landscapes shaped by permanent crops or in Scandinavian agricultural landscape dominated by forests. A more holistic approach to biodiversity that includes semi natural areas should be considerend in apan-European context.

Yet, this result suggests that there might be non-mixed landscape with a relatively high agricultural ecosystem services and biodiversity provision, and it is questionable if promoting mixed farming in those area could be contra productive.

One of the few patterns identified is that livestock dominated non-mixed landscapes are much more unlikely to close nutrient cycles. Promoting more mixed farming system in those area could enhance circularity and therefore reduce environmental pressure of agriculture.

Yet, some of these livestock dominated landscapes are found in landscapes shaped by permanent grassland. The suitability mapping has shown that these grasslands shaped landscapes have only little options to become more mixed. It will therefore be difficult to support the emergence of more mixed landscape in those areas, as currently existing mixed farming system do not arise in such a context. This however does not exclude that new forms of mixed farming systems could be developed there.

In crop dominated non-mixed area, there are more options allowing the emergence of more mixed landscapes. Preliminary results show that achieving this does not necessarily require more mixed farms, and can be achieved by promoting a good mix of complementary specialized farms.

Abbreviations

D	Deliverable
EC	European Commission
WP	Work Package
WT	Work Task

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1 Introduction

1.1 Context of the study

The agricultural sector is currently under tension (Feindt et al., 2019). A growing societal demand insists on the assurance of food security, support for farmers' livelihoods, promotion of (bio-) diversity and provision of a fair share of renewable energy production (Kleijn et al., 2012; Snapp et al., 2005; Tscharntke et al., 2005a). At the same time, agricultural production faces diverse challenges, including, among the most pressing, climate change (e.g., increasing frequency of extreme weather events), disruption of nutrient cycles, degradation of soil, biodiversity loss, price volatility, demands for different animal welfare regulations, and constant policy changes. Historically, agricultural intensification and concurrent specialization facilitated a significant increase in productivity over the last century. However, the fulfilment of economic demands came at the environment’s cost through a reduction of ecosystem service provision and biodiversity loss (Tscharntke et al., 2005b).

Ecosystem services are goods and services derived from (agro-)ecosystems that benefit human life and well-being but are not necessarily valued in the market (World Resource Institute, 2003). Services provided by agriculture (*i.e.*, agricultural ecosystem services), go beyond the provision of food production and include, for example, the support of soil formation and the nutrient cycle, water and air quality regulation or carbon storage (Mitchell et al., 2020). Thus, agricultural ecosystem services consider all major services, *i.e.*, supporting, provisioning, regulation and cultural services (Slámová et al., 2021; Swinton et al., 2007). Furthermore, agricultural land provides habitat for more than half of all species, and agriculture represents one of the largest pressures on biodiversity loss (Penko Seidl and Golobič, 2020; Tscharntke et al., 2005a). Since farm boundaries do not bind ecological processes, agricultural ecosystem service and biodiversity (ESB) provisions depend on activities and practices. In addition, ESB provision depends on the farm site, *i.e.*, where farming activities and practices take place, including neighbouring farms, the interaction with natural and semi-natural habitats in the farm’s surroundings and the usage of natural resources. Consequently, the assessment of ESB requires an approach that goes beyond farm level and field scale (Dalgaard et al., 2003).

Landscape ecology focuses on the interaction between human activities and ecological processes and, thus, derives ecosystem services based on the concept of landscapes. Following the landscape ecology literature, the landscape is defined as a “*level of organization of ecological systems that is higher than the ecosystem level […] characterised essentially by its heterogeneity and its dynamics partly governed by human activities*” (Burel and Baudry, 2003). This approach has been expanded recently by metrics that recognize agricultural landscape dynamics caused by the interaction of farming practices, natural resources and landscape patterns incorporated in the landscape agronomy (Benoît et al., 2012). These agricultural landscape dynamics impact the provision of ecosystem services and biodiversity.

Most studies on the ecosystem services provision of agriculture focus on one cropping system (see e.g., Leh et al., 2013; Murgue et al., 2016; Power, 2010) or farming practice (e.g., (Kearney et al., 2019)), while comprehensive landscape-scale approaches are limited by their focus on specific landscapes such as (Willemen et al., 2008). In this regard, the landscape scale serves as an integrative approach in which the complexities of multiple relational networks of land users, managers, ecological functions, and processes can be understood and incorporated into the agricultural landscapes (Hossard and Chopin, 2019; Meuwissen et al., 2019). The scale of agricultural landscapes allows to adequately incorporate landscape patterns, dynamics, and interactions – *i.e.*, various interactions of farm and non-farm actors and ecosystems – by acknowledging that ecological processes are not bound to the farm level (Farina, 2006). Nonetheless, in recent years, a trend towards studies with increasing attention to agricultural landscapes, agricultural classification and provision of agricultural ecosystem services can be observed in Europe. The focus on agricultural landscapes in research approaches is needed due to the diversity of agricultural landscapes at a high density, and the large share of agricultural subsidies from the European Union (EU) budget (Hossard and Chopin, 2019). However, approaches that compare different agricultural landscapes across Europe beyond economic indicators are scarce (Andersen, 2017; van Ittersum et al., 2008). This is particularly problematic as this gap is stopping EU-level policy makers at understanding which combinations of agricultural activities can lead to agricultural landscape composition that enhance provision of ESB and how to adjust specific agricultural policies, and where those investment can efficiently support the emergence of the right combination of activities.

1.2 Task 3.3 of the MIXED Project

1.2.1 Objective of the task

The work package 3 of the MIXED project aims at assessing efficiency and resilience of landscape from a bottom-up and from a top-down approach. In the bottom-up approach landscapes are seen as a set of farms with functional interactions (e.g., exchanges of feed, manure, or information). Simulations will be undertaken with an agent-based modelling approach to identify the roles of farms in the landscape (Grillot and Accatino, 2022). The top-down approach will characterize mixed farming landscapes based on land use and land cover. The two approaches will then be compared for selected networks.

Task 3.3 is focusing on the top-down approach, focusing on understanding mixed farming system from a landscape perspective. It has the following aims: (i) determining relevant indicators to characterise mixed landscapes in Europe using widely available datasets such as FADN, EUROSTAT and GIS mapping layers and (ii) identifying regions with the highest potential for a mixed farming system using statistical methods to generate classes of varying potential for mixed farming and ecosystem services.

1.2.2 Operationalization of the task

This task had foreseen the use of FADN data, which was requested at the very onset of the project. Yet the data was only provided after one and a half years into the project. When it became clear that FADN data would be delayed, objectives of the task were revisited and develop concepts and methods across a broader range of disciplines than originally envisaged were explored to find a way to achieve the objective of the task with less data than expected. Given the strong landscape focus of this task, and the fact that lots of agricultural data is available openly in some aggregated form, not having access to individual FADN data, was not highly problematic. It was rather an opportunity to sharpen our concepts, which lead to a clear separation of the dynamics at the farm and landscape levels. The farm level dynamics is addressed in task 6.2, therefore this deliverable focuses on the landscape level only. We illustrate how cross-scale interactions could be assessed, a topic that is further developed in task 6.3. We are convinced that separation between the two levels benefits the project and helps us having clearer understanding of cross-scale interaction which will help us providing more meaningful policy advice.

1.2.3 Research question retained for this task

To meet the objectives of task 3.3, five research questions were delivered:

1. *How to classify all European landscapes into different classes of combinations of agricultural activities observed at landscape scale?*
2. *How to identify landscape classes of landscapes that can be considered "mixed agricultural landscapes".*
3. *What is the relationship between agricultural ecosystem services, biodiversity provision, and mixed agricultural landscapes?*
4. *Which non-mixed agricultural landscapes can be found in similar contexts to the mixed one and therefore can be seen a priority areas for policy?*
5. *Which farm types lead to the emergence of a mixed agricultural landscape?*

This deliverable presents the concepts to address these research questions and the overall approach developed with a suite of methods from different disciplines to assess the linkage between mixed agricultural landscape and ecosystem service delivery. It shows how we applied the proposed approach to a broad range of open access data, to identify mixed agricultural landscape, assess their provision of ESB as well identify priority areas for policy. Finally, we discuss the implication of this results both for future scientific research as well as for policy makers.

2 Conceptual framework

2.1 Core concepts to define mixed landscapes

Working at landscape scale is the agricultural sector is not very common, and there is a need to clarify how the different disciplinary concept we bring together are linked to each other. To develop a conceptual frameworks that brings all elements together, core concepts necessary to understand "mixed landscape": *landscape scale*, *farming system* and *ecosystem services* are reviewed in this section.

2.1.1 The landscape scale

The starting point is the concept of *landscape* derived from landscape ecology, which studies ecological processes in the environment and particular ecosystems with a focus on the relationship between patterns, process and scale. Landscape ecology integrates a biophysical and analytical approach with a humanistic and holistic perspective. Hence integrating natural and social science. In this perspective, landscape can be understood as a geographic extent composed of interacting ecosystem clusters. Given the strong focus on agriculture in the mixed project, we focus on agricultural landscape, that are landscapes in which faming activities take place, and exclude landscapes that are solely shaped by semi-natural and natural processes. As a result, an agricultural landscape is a geographical extent in which farming activities and their specific practices are interacting with the ecosystems.

2.1.2 Farming systems

Farming systems has a multitude of definitions that can be linked to different scales (Giller, 2013). For our work we follow Meuwissen et al. (2019) defining farming systems as local networks of farmers and various other actors – embedded in specific socio-economic and agro-ecological contexts – that cooperate, compete, and otherwise interact. From this definition, we can derive that an agricultural landscape is shaped by a farming system, hence a network of farmers and other actors, that interact with the ecosystems.

Indicators useful for characterizing a farming system observed at landscape scale, are land use in terms of share, intensity and diversity composition. They serve as a useful analytical approach to assess and describe farming systems, while reducing system complexity for analytical purposes and understanding.

2.1.3 The farm and its links to the farming landscape scale

The farm can be considered a unit that produces private rural goods and services, *i.e.* services for which the farmers receive payments, along with some public goods. Next to primary food production, such as crops, feed or livestock, private rural goods and services also encompass activities that require the assets of the farm but are not primary food production, such as on-farm tourism or catering, on-farm processing or retail but also payments directly linked to the provision of ecosystem services through agroecological schemes (Meraner et al., 2015). This definition is broader than the classical definition of farm diversification (Meraner et al., 2015) to encompass both strategies aiming to engage in the cultivation of different crops, or a combination of crop and livestock activities, as well as non-primary food production activities such as tourism or catering. Mixed farms are combinations of different farm enterprises, particularly crop enterprise, with livestock- or tree-related enterprises.

While rural private good and services provided by individual farmers can be linearly aggregated to the landscape, the impact of the production of those goods and services on the environment are highly complex and context-specific. At the landscape level, the ecosystem and biodiversity are not merely the sum of the rural goods and services provided by farmers. The network of farmers might form synergies or lead to inefficiencies that need to be accounted for. Thus, agricultural landscapes are not upscaled products from farms or fields to the landscape scale (Dalgaard et al., 2003; Silva et al., 2020).

2.1.4 Farming system functions: ESB provision

ESB are the many and varied benefits to humans provided by ecosystem functions and encompasses supporting, provisioning, regulating, and cultural functions. ESB offer a framework to assess the complex interaction of the farming system, so the network of farmers as a whole on the ecosystem. Some ESB are directly influenced by the network of farms and are the result of interaction of different individual farm activities as well as complex interaction of those activities with the ecosystem. For example, one supporting service is nutrient cycling, which can be achieved in two ways: each farmer within the landscape can achieve a closed nitrogen cycle having the right mix of crop and livestock activities, alternatively the nitrogen cycle can be closed by having a network of different specialized farms, each not closing the nitrogen cycle, yet closing cycle as a group. How to achieve a closed nitrogen cycle will also depend on biophysical factors such as soil type or climate, both driving factors of nitrogen leaching.

2.2 A cross-scale framework

Bringing all the concepts together led to the following framework (Figure 1).

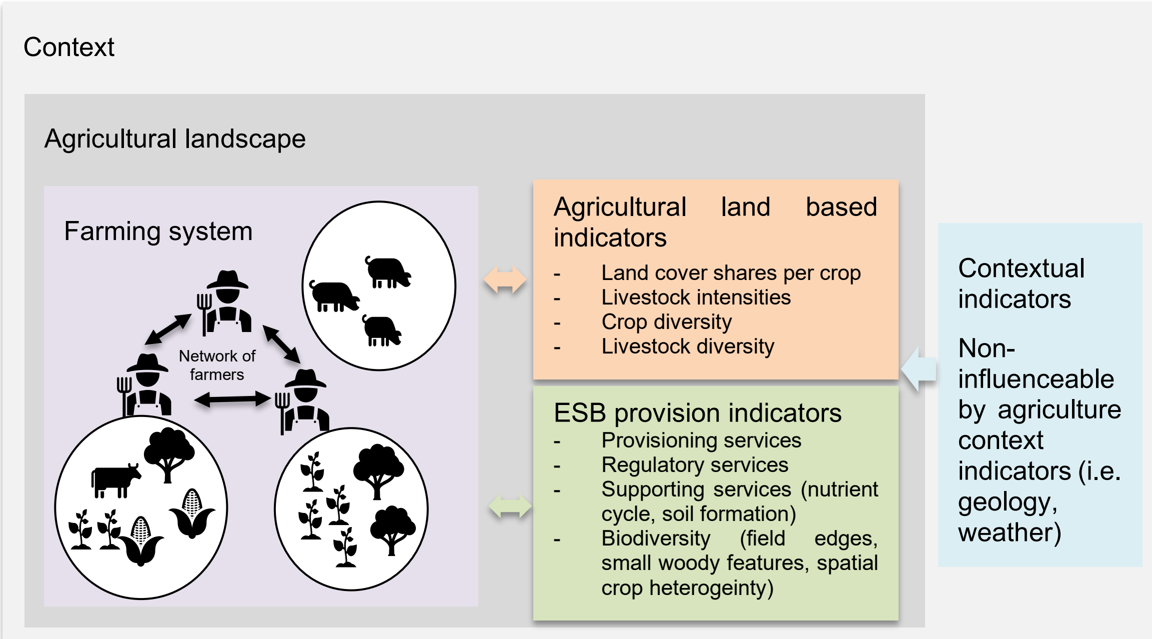


Figure 1: the conceptual framework developed for task 3.3

Agricultural activities occur in farms, where farmers combine different farm enterprises, which can be related to crop, livestock, agroforestry but also related to farm diversification such as tourism or payment for eco-schemes. A smart combination of crop-livestock integration activities can enhance on-farm circularity and resilience through enhanced diversity. Some of these synergies can also be achieved when farmers collaborate, e.g., through the network. As a result, impacts at landscape and regional scales are not merely the sum of the impacts observed at farm the level, but can be observed through assessing agricultural activities through agricultural land-based indicators. These indicators need to capture the importance as well as the diversity of crops, trees and livestock. Relative crop production can be assessed with the relative share of a land use for a specific crop. Relative livestock production can be assessed in terms of livestock unit per livestock species per hectare utilized agricultural land.

The farming system provides a whole range of ESB resulting from the farm network. At landscape scale, we focus on those services that are linked to biophysical ecosystem processes, namely the provisioning, regulating and supporting services, and assess ESB in relation to farming indicators must be based on metrics that can be directly influenced by agriculture. While this is straightforward for provisioning services where agriculture produces food and feed, it is more complicated with the supporting services. Nutrient cycling and soil formation are the two supporting services directly influenced by agriculture. Regulatory services are very diverse and encompass purification of water and air, climate regulation, pollination, biological pest control. Because the concept of ecosystem services was often criticised for excluding the biodiversity as inherently valuable, it is important to include biodiversity indicators as such.

Finally, there is a range of external factors, and conditions that agriculture and its policy cannot influence in the long term, such as geology, climatic condition but also remoteness or social norms. We refer to this as context, that obviously puts sharp constraints on farmers' decision-making processes and management (Meuwissen et al., 2019).

2.2.1 Definition of mixed agricultural landscapes

From the above conceptual framework, agricultural landscapes are characterized by the agricultural land-based indicators related to land cover, production intensities and diversity of land uses. Mixed agricultural landscapes are those in which a high diversity of crops, both annual and perennial, as well as livestock activities take place within the landscape. As a result, there can be mixed cropping landscape, with a high diversity of cropping activities observed at the landscape scale, mixed livestock landscapes, with a high diversity of livestock activities observed at the landscape scale, and mixed crop-livestock landscapes where a high diversity of crop or livestock activities is combined with a relatively important diversity of the other type of activities.

3 Material and methods

3.1 Study area and landscape definition

The case study area covers the EU and the United Kingdom (UK) at NUTS 2 (Nomenclature of territorial units for statistics: basic regions) resolution. Commonly, agricultural landscapes are delineated by biophysical criteria, such as watersheds. In fact, anthropocentric structures are often levels on which data is reported and thus better equipped in contrast to biophysically structured landscape definitions (Carvalho-Santos et al., 2016; Fan and Shibata, 2015; Frey et al., 2013). Such a biophysical delineation is however problematic with socio-economic data, that is collected following sampling strategies and is only representative within the sampling units. For European agricultural statistics, data is representative at the NUTS 2 administrative delineation, or higher. For this task, NUTS 2 is chosen as landscape delineation, and contextual indicators were computed to match these delineations.

Originally, Europe has 242 NUTS 2 regions in the so called 2013 definition. However, not all data are provided with this geographic definition. Some countries such as France or Greece reported their agricultural data in older and different versions of NUTS2 and Germany reported the data at NUTS1 level only. The landscape definition used in this study is a modified 2013 NUTS2 with 234 NUTS 2 regions, shown in Figure 2.

In addition, some NUTS2 were eliminated, namely Overseas departments of France as well as Spanish cities and regions in Northern Africa and the Canary Islands are not covered since their agro-ecological zones highly differ, which complicates transferability as well as all NUTS2 with lower less than 10% UAA (mainly found in Scandinavia)

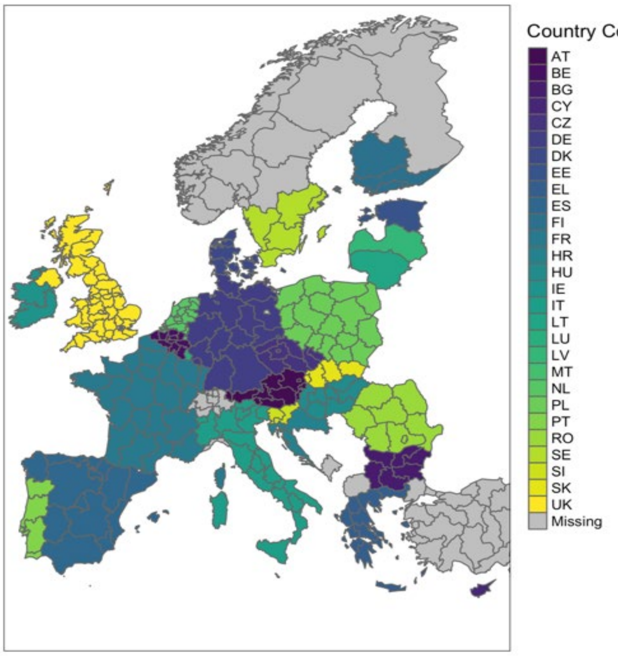


Figure 2: EU NUTS 2 case study area by Eurostat country code ("Missing" refers to the excluded NUTS 2 regions) (Eurostat - European Commission, 2015, 2011)

3.2 Data

A broad review of secondary open access data was performed and reviewed for its potential of assessing particular dimensions in the conceptual framework. Table 1 shows the datasets that were retained for this study, their raw format and their sources.

Table 1: retained of dataset including the dimension covered in the concpetual farmework

Data	*Raw format (units)*	*Indicator type*	*Variables of interest*	*Source*
Farm statistics	Table (NUTS2)	Agricultural land based	Utilized agricultural land Eurostat Farm type	Eurostat : ef_kvftreg
Cropland and grassland area	Table (NUTS2)	Agricultural land based	Area for each individual crop / grasslands type in Eurostat	Eurostat ef_lus_allcrops
Livestock population	Table (NUTS2)	Agricultural land based	Numbers of animals for different animal class, namely horses, bovine, swine, sheep, goats and poultry in terms of heads and LSU, for details see in the appendix.	(Eurostat – European Commission, 2021a) ef_lsk_main
Crop yields	Raster map (5 arc minutes)	ESB (provisioning service)		GAEZ v4 (FAO and IIASA, 2021a, 2021b; Fischer et al., 2021)

Milk yield	Table (NUTS2)	ESB (provisioning service)	Raw cow milk (D1110A) in ton was converted to price	Eurostat agr_r_milkpr
Soil cover and tillage	Table (NUTS2)	ESB (provisioning service)	Areas under different cover crops and tillage.	Eurostat ef_mp_soil
Nitrogen balance	Table (NUTS1)	ESB (supporting service)	Nitrogen balance (BAL_UAA)	Eurostat aei_pr_gnb
Phosphorus balance	Table (NUTS2)	ESB (supporting service)	Phosphorous balance	(Einarsson et al., 2020)
High resolution crop maps of 2018	Raster map (10m)	ESB (biodiversity)	Crop types	EUROCROP (d'Andrimont et al., 2021)
Small woody feature 2015	Raster map (100m)	ESB (biodiversity)	% of small woody feature	(Copernicus Land Monitoring Service, 2019)
Climatic condition	Raster map (30 sec)	Contextual	Bioclimatic data	WorldClim (Fick and Hijmans, 2017)
Digital elevation model – based on SRTM4.1	Raster map (1km)	Contextual	Elevation, slope, aspect, northness	(Amatulli et al., 2018)
Soil properties	Raster map (250m)	Contextual	% of clay content at 15 cm depth % of sand content at 15 cm depth	SoilGrid (Hengl et al., 2017)
Travelling distance to cities of more	Raster map (1 km)	Contextual	Travel time to cities population < 50 000 Travel time to cities population < 5 000	(Weiss et al., 2018)

3.2.1 Building the agricultural land-based indicators

Most agricultural indicators are derived from Eurostat[1] and come from the farm structure survey. Data in this survey are available from 2005 to 2016. The average from 2013-2016 was retained to smoothen eventual outlier years. To compute the agricultural land-based indicators for the different crop and livestock activities for the analysis the raw data needs to be made comparable across the different landscapes. The crop data containing the area cropped for each crop which was converted into a share relative to the total utilisable agricultural area (UAA) by computing for each crop *i* in landscape *k* divided by the UAA of the landscape: $crop\_share_{i,k} = \left(area\ crop\ _{i,k}/UAA_k\right)$. The livestock data contains both livestock heads and livestock units (LSU) for livestock. These data were transformed into livestock units for each species *i* in landscape *k* per hectare of UAA. $livestock\ intensity\ _{i,k} = \left(LSU\ _{i,k}/UAA_k\right)$. Table B in the appendix includes a detailed list of all livestock species and their Eurostat codes. These data where aggregated where necessary to fit the NUTS2 definition landscape definition (shown in Figure 2)

[1] These data were extracted with the EUROSTAT package in R

3.2.2 Building the ESB indicators

For each provisioning, supporting service and biodiversity, a range of specific indicators were created based on the raw data. Given the lack of data that allow the assessment of meaningful regulatory services from agriculture, these were not addressed.

3.2.2.1 Provisioning services

Provisioning services were assessed as the yield of major crops produced in a landscape. As this data is not available in Eurostat, the actual yields from the GAEZ database were used. This is a geographical dataset at the resolution of 5 arc minutes, which was aggregated to the landscape definition (NUTS2) with a zonal statistic. Yield in the GAEZ is in harvest weight in ton/ha for single crop but yield data for aggregated and rather heterogenous groups (e.g., vegetables) in reported volumes per hectares (in 1000 $/ha). Single crops converted into $/ha based on international price weights derived from FAO (Geary-Khamis Dollar of year 2000). To assess livestock productivity, the average raw milk production from Eurostat from 2010-2020 was used. This was also converted into dollars using the median producer price for Europe from the FAO database, which was 280 $/ton. Unfortunately, there is no dataset about the amount of meat or egg produced in a specific landscape.

3.2.2.2 Supporting services

Supporting services consisted of nutrient cycles and soil formation. For the nitrogen cycle we relied on Eurostat providing a gross nitrogen balance value for each country. This was disaggregated to the NUTS2 by assigning the value of the country to each landscape within the country.

For the phosphorous we relied on Einarsson et al. (2020), which provides data at the NUTS2 level. The phosphorus balance value was retained and aggregated where necessary to fit our landscape definition (shown in Figure 2).

For the soil formation we relied on the Eurostat that provides information about soil tillage and cover crop at NUTS2 level. It presents percentage of land under specific tillage or cover crop practices. For details, please see the appendix.

3.2.2.3 Biodiversity indicators

Biodiversity is difficult to measure, and it is even more difficult to find biodiversity indicators related to agriculture. We decided to retain three different metrics:

1. *Spatial heterogeneity of crop species*. Recent research has shown that crop heterogeneity in the landscape plays an important role in biodiversity (Aramburu Merlos and Hijmans, 2020; Sirami et al., 2019).
2. *Density of field edges*. Sizes of agricultural fields in the landscape is a major driver of diversity and abundance of farmland biodiversity (Clough et al., 2020; Martin et al., 2019). Smaller field size results in more field edges that provide different habitat types (Ricciardi et al., 2021).
3. *Density of small woody features*. The amount and variety of available habitat on agricultural landscape is directly correlated with biodiversity levels (Fahrig et al., 2011). Patches of natural and semi-natural landcover provide critical habitat to a wide variety of species to travel through agricultural landscape (Pasher et al., 2016). In landscapes, small woody features, such as hedgerows, be it permanent natural vegetation or planted and heavily managed features are essential elements nature-friendly mosaic supporting both humans and nature (Kremen and Merenlender, 2018).

Two of the these metrics, (spatial crop heterogeneity and density of field edges) were computed with the landscape metrics Rpackage (Hesselbarth et al., 2019) on the Eurocrop 10m resolution map, showing which crop is growing where.

The spatial crop heterogeneity was computed with the Shannon evenness index (SHEI), and is a measure of dominance. The SHEI ranges from 0 to 1 where 0 suggests there is a dominant crop while 1 suggests that different crops are evenly distributed in space, and no crop is dominant, denoting thereby a diverse area. The SHEI was computed for each landscape.

The field edge metric was assessed by calculating the average field size. This was computed with the so-called SPLIT for each landscape. The SPLIT is an aggregation metric, that describes the “patchiness” of landscape, counting the numbers of patches within a landscape. If there is only 1 patch the SPLIT is equal to 1 and increases as the number of patches increases. Because our input data refers to crop, a patch is a field. The higher the SPLIT the smaller are the fields in that particular landscape.

The third metric captures the amount of small woody features. This was computed based from the Copernicus map and represents the percentage of the area classified as “small woody feature” on a 100 square meter. Based on this dataset, we computed the area with small woody features in a landscape. To make this metric comparable across landscapes we divided this area by the UAA.

3.2.3 Farm level data

To explore the relationship between activities observed in single farms and the landscape outcome, the farm basic statistic was used. Farm types that are available in Eurostat were used. This classification retains 9 farm types, namely: (1) specialist field crop, (2) specialist horticulture, (3) specialist permanent crops, (4) specialist grazing animals, (5) specialist granivores, (6) mixed cropping, (7) mixed livestock, (8) mixed crop livestock, (9) non classifiable. We kept the number of farm holding for each farm type Eurostat definition. For each landscape k we computed the percentage of farms in each farm type i $\% farm_{i,k} = \left(\# farm_{i,k} / \sum_{i=1}^{n} farm_{i,k}\right)$

This Eurostat classification is based on economic output, and not on physical activities or enterprises. This implies that mixed farms that have a particular enterprise that non-profitable relatively to the other enterprise, might be classified as specialized farm. In principle this part could be replaced by a much finer typology based on individual FADN data and be based on physical output.

3.2.4 Contextual indicators

Contextual indicators that have an influence on agriculture but agriculture cannot influence them in the short and medium term. All of them are maps in the raster format.

To capture the agro-climatic conditions, worldclim data and its bioclimatic were used, shown in detail in the appendix. Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables.To capture the topography, we rely on the SRTM v4 digital elevation model. For this dataset we retained elevation, slope and aspect to capture exposure to the sun. Soil properties come from the soilgrid maps, we considered the percentage of clay and sand at 15 cm depth. To capture the distance to markets, we considered the travelling time to cities more than 50 000 people and travelling time to cities with more than 5 000. These are all raster data, they have been resampled using worldclim as reference raster.

3.3 A suite of geostatistical approaches

To answer the research questions raised in task 3.3 we developed a suite of statistical and geo statistical approaches in 5 steps (Figure 3).

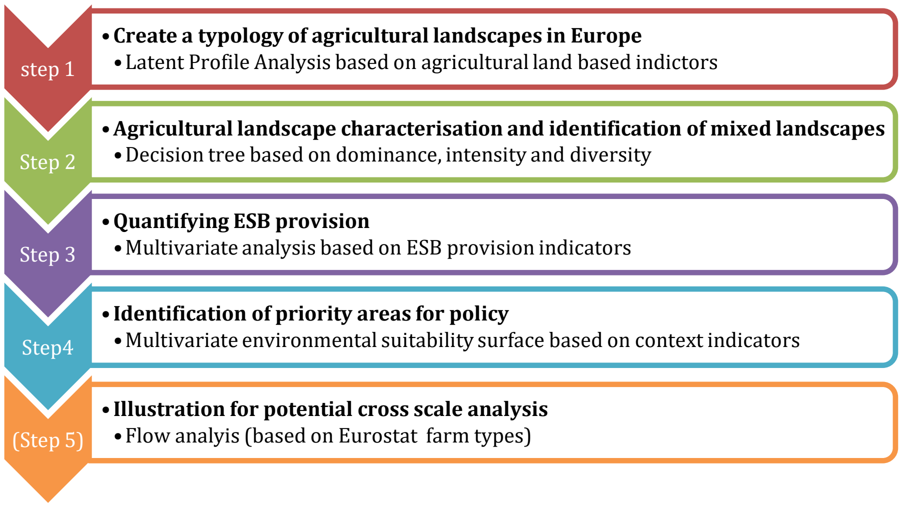


Figure 3 : the 5-step approach applied in task 3.3 of the MIXED project to answer the different research questions

3.3.1 Step 1: create a typology of agricultural landscape in Europe

Agricultural landscapes are grouped according to similarities based on their agricultural production. For such a classification, we used the latent profile analysis (LPA) a latent class model, that is a particular case of mixture models. (Oberski,2020) accurately describes "[m]ixture models [as] the art of unscrambling eggs: it recovers hidden groups from observed data." The LPA is a mixture model that uses a model-based clustering technique in which multi-dimensional continuous data can be categorized into latent classes. In contrast to other traditional clustering methods such as *k*-means (D'Amico et al., 2013) and hierarchical clustering (Silva et al., 2020) that base their algorithms on heuristics which directly derive the clusters from the data, LPA incorporates probability and uncertainty measures into the cluster mapping. Thus, each observation contains a probability to be assigned to each cluster, hence, the highest probability value determines each assignment. Additionally, the model-based clustering approaches automatically search for the optimal cluster amount (Boehmke and Greenwell, 2020; Fraley et al., 2012, 2007; Scrucca et al., 2016; Spurk et al., 2020).

Applying LPA to continuous data creates latent profiles based on the assumption that unobserved heterogeneity can be found in the dataset. Thus, the profiles represent the sub- distribution of the data into differentiable descriptive statistical parameters. Moreover, LPA keeps a certain degree of flexibility due to the recognition of the fact that identified classes are uncertain (Boehmke and Greenwell, 2020; Oberski,.; Spurk et al., 2020). Traditional clustering methods are widespread in agricultural landscapes classification approaches, e.g., (Andersen, 2017; D'Amico et al., 2013). In contrast, selecting LPA as a clustering tool is innovative in this research field and means that unobserved patterns in agricultural production, have been assigned to clusters on the basis of probabilities and uncertainties of the probability distribution of the observed agricultural activities (Bauer, 2021).

The LPA was applied to the agricultural land based indicators (Table 1), resulting in different groups of landscape that can be considered as similar, we will hereafter refer as landscape class.

3.3.2 Step 2 : Agricultural landscape characterisation and identification of mixed landscapes

3.3.2.1 Decision rules

The typology resulting from last step of our procedure does not yet allow to identify mixed agricultural landscapes. Decision rules were developed to characterize the different landscape classes, and identify those that are mixed. These decision rules are based on the median value of land-based indicators per class. Three types of rules were defined. First, a rule to identify if an activity is dominant, second if an activity is intensive and third how diverse activities are. The three types of rules were applied to crop and livestock separately, as shown in Table 2.

Table 2 : decision rule to label landscape classes

	Crop related activities	Livestock related activities
Dominant activities	A crop *i* is considered dominant for class *j*, if its median crop share for crop *i* is bigger than the third quintile of the distribution of median crop share *i* observed for the landscape classes, (upper 40% of the distribution of the classes).	A livestock species *i* is considered dominant for class *j*, if its median lsu/ha of species *i* is bigger the third quintile of the distribution of the median lsu/ha of species i observed for the landscape classes (upper 40% of the distribution of the classes)
Intensity	-	A class j is considered as extensive if total LSU of all species per hectare is smaller than the first quartile of median intensities observed for the landscape class (lower 33% of the distribution and intensive if total LSU of all species per ha is bigger than third quartile of the median LSU of all species (upper 33%)
Diversity (Shannon Weaver diversity index - SDI)	Crop diversity for class j is high when the Shannon Weaver diversity index for the class j computed to the median of each crop is bigger than the second tertile (upper 33%) Crop diversity for class j is low when the Shannon the class j computed to the median of each crop is smaller than the first tertile (lower 33%)	Livestock diversity for class j is high when the Shannon Weaver diversity index for the class j computed to the median of each lsu/ha for each species is bigger than the second tertile (upper 33%) Livestock diversity for class j is low when the Shannon Weaver diversity index for the class j computed to the median of each lsu/ha for each species is smaller than the first tertile (lower 33%)

An activity, expressed as crop share in relation to UAA for a specific crop or expressed as livestock unit per hectare for a specific livestock species is considered dominant when it is part of the upper 40% of the distribution of observed at landscape class level. More particularly an activity was considered dominant if it is bigger than the third quintile. Intensity rules could only be applied to livestock activities. It considers total LSU, so for all species together. If a class is found within the upper 33% of the distribution then the class is considered intensive, and if it is part of the lower 33% it is considered as extensive. Both dominance and intensity were used to label the class and characterize them in more details. Finally, diversity was assessed with the Shannon Weaver diversity Index (SDI), again for crop and livestock. If the class is found with the upper 33% of the distribution then the landscape class was considered as highly diverse or in crop or livestock activities and if the class was found in the lower 33% it was considered as low diversity.

3.3.2.2 Defining mixed landscape

While the rules above allow characterizing landscape, mixed agricultural landscapes have not yet been identified. Figure 4 shows the set of rules that allow to identify different categories of mixed agricultural landscape. All landscape were classified into low medium and high diversity based on terciles. Landscape with a high diversity for crop activities and a medium to high diversity in livestock or the other way around are considered as mixed crop-livestock landscape. A high diversity for crop but low for livestock, refers to a mixed crop landscape and if a high diversity for livestock diversity combined with a low crop diversity is referred as a mixed livestock landscape. All other landscapes are considered as non-mixed.

Diversity livestock activities / Diversity crop activities	High	Medium	Low
High	Mixed crop – livestock landscape	Mixed crop – livestock landscape	Mixed crop landscape
Medium	Mixed crop – livestock landscape	Non – mixed landscape	Non – mixed landscape
Low	Mixed livestock landscape	Non – mixed landscape	Non – mixed landscape

Figure 4 : rules to identify different categories of mixed landscapes

3.3.3 Step 3 : quantifying ESB provision

Three types of ESB were retained, namely supporting and provisioning services as well as biodiversity. Assessing these ecosystem services is not straightforward, as they need to be measured indirectly. As a result, many different indicators can be used to assess a certain type of ecosystem service provision and these different indicators are likely to be correlated. To come up with one consolidated indicator for which many variables are available that are correlated, a data reduction with a PCA was applied as described in the appendix.

Table 3: consolidated ESB indicators and their computations

ESB	FINAL CONSOLIDATED INDICATOR	DATA PROCESSING
SUPPORTING SERVICE	Nutrient cycles	First PCA loading on nitrogen and phosphorus balance
	Soil formation	First PCA loading on each separate tillage and cover crop
PROVISIONING SERVICE	Food and nonfood provision	First PCA loading the crop and milk yields in values.
BIODIVERSITY	Crop heterogeneity	Original data
	Density of field margins	Original data
	Small woody features	Original data

Each landscape as well as landscape classes can be compared along these ESB indicators. As a result, in this step we can compare the ESB provision in mixed agricultural landscape and in non-mixed agricultural landscape.

These indicators are very heterogeneous, and are likely not to be distributed normally. To make the ESB comparable and accounting for the fact that their distributions are highly skewed, the ESB indicators were assigned the rank based on quintile, where 1 suggests that the value is among the lowest 20% of the distribution and 5 is suggesting that the landscape is among the highest 20% of the distribution. This allows to compare different agricultural landscapes and qualify their provision as very low, low, medium, high and very high compared to others.

The interpretation of the rank concerning the nutrient balance is opposite. A negative or a net zero balance indicates a good ecosystem provision, it got the score 5; as the balance becomes positive the ESB diminishes. A detailed analysis of the individual and the consolidated data has shown that lower nitrogen and lower phosphorus are found in the lowest quintile of the first PCA loading (see Appendix Figure 1).

3.3.4 Step 4 : Identification of priority areas for policy

From the previous step we can identify mixed agricultural landscapes with a high ecosystem provision. To understand priority areas for policy, we explore in which context these mixed agricultural landscapes with high ESB provision have emerged. Finding areas with similar context, suggest that the conditions are met in which a similar mixed agricultural landscape can emerge.

For this step we apply a multivariate environmental similarity surface (MESS), an index that represents how similar a point in space is to a reference set of points, with respect to a set of predictor variables (Elith et al., 2010). This modelling approach was originally developed for species modelling also known as ecological niche modelling, discover potential novel habitats for plants. The algorithm is based on the maximum entropy principles and relies on presence-only data. In its simplest term, the algorithms compare the distribution of contextual variables where a given plant was found and looks on the map for other location with similar distributions.

We apply this method to the distribution of the contextual indicators within the particular landscape of interest (NUTS2), namely mixed agricultural landscapes and identify locations in Europe where a similar distribution of contextual variables is found.

All geographic contextual variables that were aggregated where revisited. Some variables like aspect and northness lose their meaning when aggregated to the modelling resolution of 5 km^2. Also, the algorithm cannot handle too many variables, so we retained only those that have most influence of agricultural production, namely:

1. mean annual temperature
2. maximum temperature of the warmest month
3. mean temperature of the driest quarter
4. annual precipitation
5. Precipitation seasonality
6. % of clay in soil
7. % of sand in soil
8. slope
9. Travel time to cities 50 000 < population < 50 000 000, which includes all cities bigger of 50 000 in Europe

The first 5 variables capture the climatic condition as well as possible constraint for crop growth, while percent clay and sand capture the soil conditions. Slope capture the constraint of producing mechanically, and finally travel time to cities, captures a proximity to a market, seen as a potential for short supply chains, where farmers can sell directly to consumers.

The suitability map can be then used to identify locations that are today considered as non-mixed yet is situated in a context that is similar to a specific mixed landscape.

3.3.5 Step 5 : exploring cross-scale interactions

This is an exploratory step to illustrate how cross-scale interactions could be explored in the future work. We use descriptive statistics, more particularly flow diagrams, to get more insights into the farm network leading to the emergence of a mixed or a non-mixed landscape. We use the Eurostat farm typology to illustrate this process. This step is exploratory to help adjusting the work and reflections in task 6.3 about cross-scale interactions.

4 Results

4.1 Step 1 : identify similar landscape

The LPA clustered the crop-tree and livestock land use input data of the case study area in 19 final classes which are illustrated in Figure 5

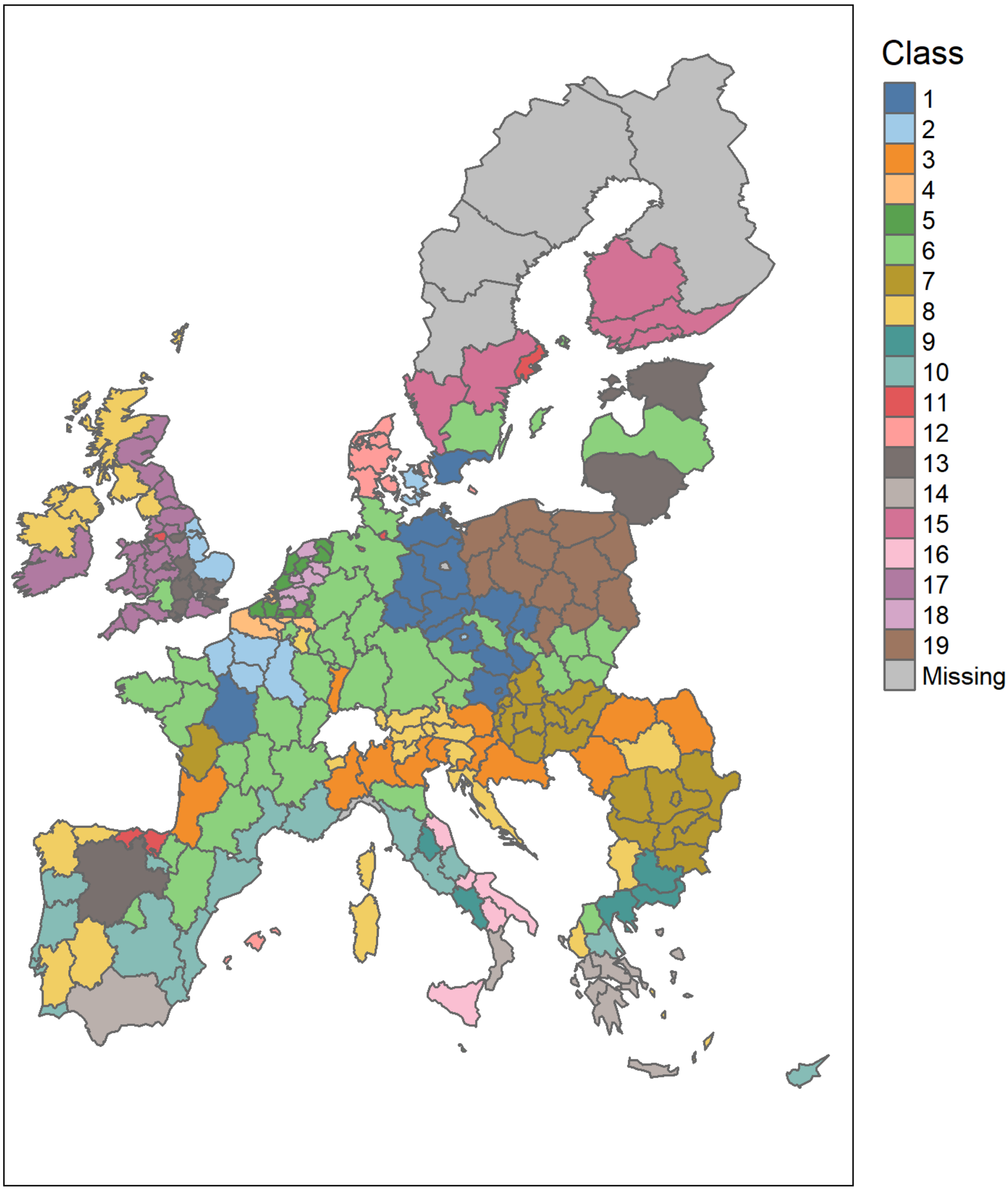


Figure 5 : EU NUTS 2 map with LPA results differentiating 19 classes ("Missing" refers to the excluded NUTS 2 regions)[2]

4.2 Step 2 : characterizing landscape and identification of mixed landscapes

Based on the LPA results and the methodological approach, classification of each class can be structured. Accordingly, the final agricultural landscape label is mainly derived by following aspects: (i) 'Dominant crop; (ii) 'Diversity in the crop; (iii) 'Intensity'; (iv) 'Dominant livestock' and (v) 'Diversity in the livestock'.

[2] The color selection for each class is conducted manually since the consideration of color blindness with a number of 19 different items and the demand to be able to distinguish each class easily from another is not provided in predefined palettes in R.

As already emphasized, main assumption of the classification process is comparability and relational explanation, *i.e.*, the classification system is created by differentiating the classes in relation to each other and thereby classifying them. This allows the conclusion of comparisons and increases their reliability. However, the authors acknowledge that some structuring elements within the farming systems are neither mentioned nor further discussed due to their low shares in comparison to the other classes (defined by quartile threshold limits), this is counteracted somewhat by including them in the figures and in some of the detailed description of each class.

Following the methodological classification approach of farming systems with respect to their diversity, Table 4 displays the results of Shannon weawer index (SDI) for the cropping and the livestock system, and, additionally, shows the comparison of both systems which, among others, serve as the basis for the final agricultural landscape definition.

Table 4 : Shannon-Weaver diversity index results for the crop and the livestock activities of different classes (red colored cells indicate a “high” result of SDI, lighter red colored cells a “medium” result)

Class	SDI of sub-categories of crop-tree types	Tertiles division of SDI crop-tree results	Classification of diversity in the crop activities	SDI of livestock categories	Tertiles division of SDI livestock results	Classification of diversity in the livestock activities	Defined as *mixed* crop livestock landscape
1	1.915	3	high	1.106	1	low	
2	1.801	2	medium	1.231	2	medium	
3	1.382	1	low	1.237	3	high	
4	1.889	3	high	0.85	1	low	
5	1.655	2	medium	1.14	2	medium	
6	1.569	1	low	0.883	1	low	
7	1.645	2	medium	1.428	3	high	x
8	0.509	1	low	1.043	1	low	
9	1.865	2	medium	1.423	3	high	x
10	1.636	2	medium	1.526	3	high	x
11	1.061	1	low	0.775	1	low	
12	1.895	3	high	0.84	1	low	
13	1.776	2	medium	1.355	3	high	x
14	1.352	1	low	1.446	3	high	
15	1.969	3	high	1.173	2	medium	x
16	1.978	3	high	1.232	2	medium	x
17	1.253	1	low	1.185	2	medium	
18	1.068	1	low	1.154	2	medium	
19	2.289	3	high	1.105	1	low	

Besides the detailed representation in Appendix Table 6, Table 5 provides an overview of the classes that are ultimately defined as *mixed* in their final class labels. They are characterized by at least one *mixed* farming sub-system, referred to in the following as ‘*mixed* agricultural landscapes’. Furthermore, the following chapters contain an in-depth description of all relevant classification aspects as well as additional information regarding the agronomic peculiarities. For each section, the relevant NUTS 2 regions are listed in the beginning.

Table 5 : Overview of *mixed* agricultural landscapes

Class	*Mixed* crop landscape
1	*Mixed* crop of dominant industrial and root crops
4	*Mixed* crop of dominant root crops and vegetables with an extensive bovine livestock system
12	*Mixed* crop of dominant cereals, and grasses with an intensive dominant swine, and horses (et al.) livestock system
19	Mixed crop of dominant cereals, pulses, and vegetables with a dominant monogastric livestock system
	Mixed livestock landscape
3	*Mixed* livestock system of dominant granivores, horses, and other species
14	Cropping system of permanent crops, vegetables, and permanent grassland with a *mixed* livestock system of dominant sheep and goats
	Mixed crop livestock landscape
7	*Mixed* farming system of dominant cereals and industrial crops in the cropping system with a dominant poultry livestock system
9	*Mixed* farming system of dominant industrial and permanent crops in the cropping system with a dominant sheep livestock system
10	*Mixed* farming system of dominant permanent crops in the cropping system with a dominant sheep and goat livestock system
13	*Mixed* farming system of dominant industrial crops and pulses in the cropping system with an intensive dominant sheep and horses livestock system
15	*Mixed* farming system of dominant cereals, pulses, and grasses in the cropping system with a dominant extensive swine livestock system
16	*Mixed* farming system of dominant vegetables, grasses, and permanent crops in the cropping system

This section describes and characterize every landscape class separately.

4.2.1 Class 1: *Mixed* cropping system of dominant industrial and root crops

Codes of the NUTS2 regions belonging to this class: AT12, AT13, CZ02, CZ04, CZ06, CZ07, DE4, DE8, DED, DEE, DEG, FR24, PL51, PL52, SE22

Class 1 is characterized by an average UAA of 46%.15 agricultural landscapes are found in this in this class, including Czech (from the Northwest of the country (CZ04 Severozápad) to Central Moravia (CZ07)), regions in Eastern Germany and neighboring Polish regions are representing this agricultural landscape class. With a “high” diversity in the cropping system and significant high shares of crop-tree types, this class of agricultural landscape has industrial crops (crops which are not normally sold directly for consumption because they need to be industrially processed) on 8 % of the UAA, in which oilseeds and root crops (4 % of UAA) with sugar beets are widespread. However, cereals occupy most (47 %) of the agricultural area as shown in

Figure 6, even if not classified as a dominant system, among which diverse types also indicated significant high values, such as cereals for the production of grain, rye, triticale, sorghum and other cereals. Additionally, the class is shaped by extensive livestock system characterized as "low" in diversity. As displayed in

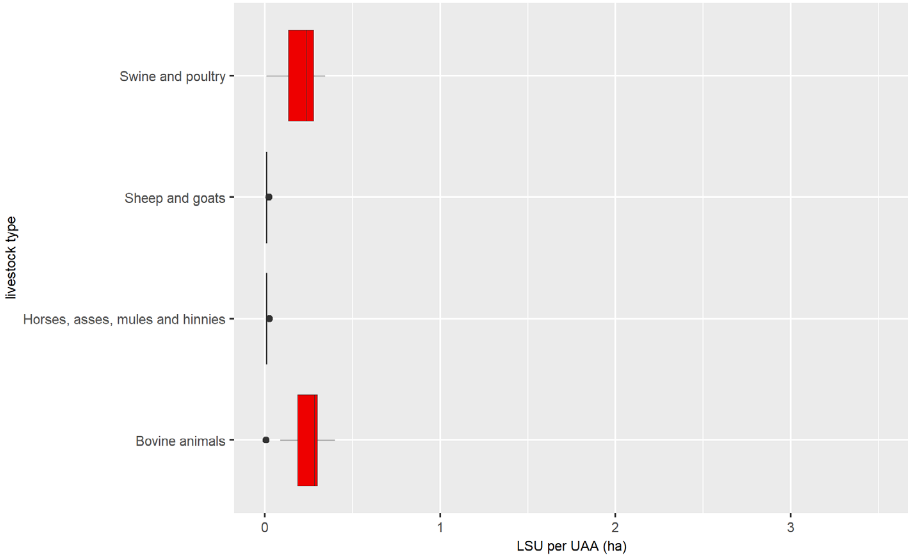


Figure 7, the agricultural landscape class contains a livestock system which does not exceed the third quartile threshold of the overall distribution, and hence, is not being mentioned in the labelling and classification process.

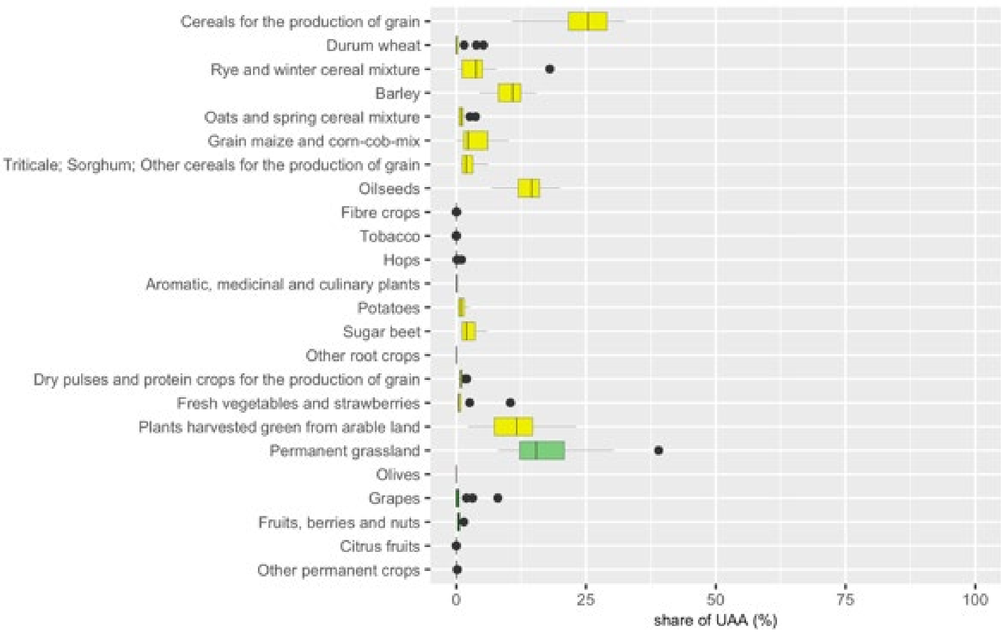


Figure 6 : Class 1: Crop-tree distribution (in the share of UAA (%))[3]

[3] Following figures which illustrate the crop distribution within the classes contain the different crop-tree types which have been included in the LPA beforehand.

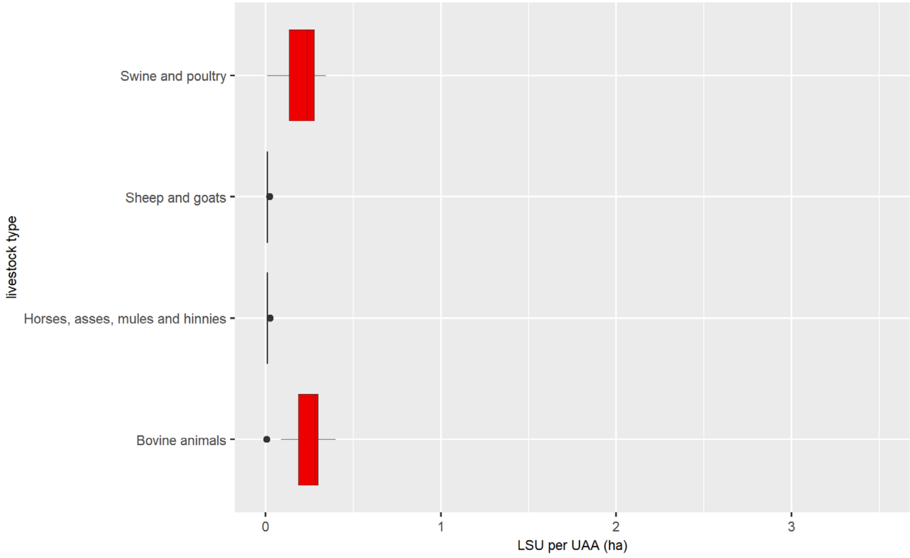


Figure 7 : Class 1: Livestock distribution (in LSU per UAA (ha))

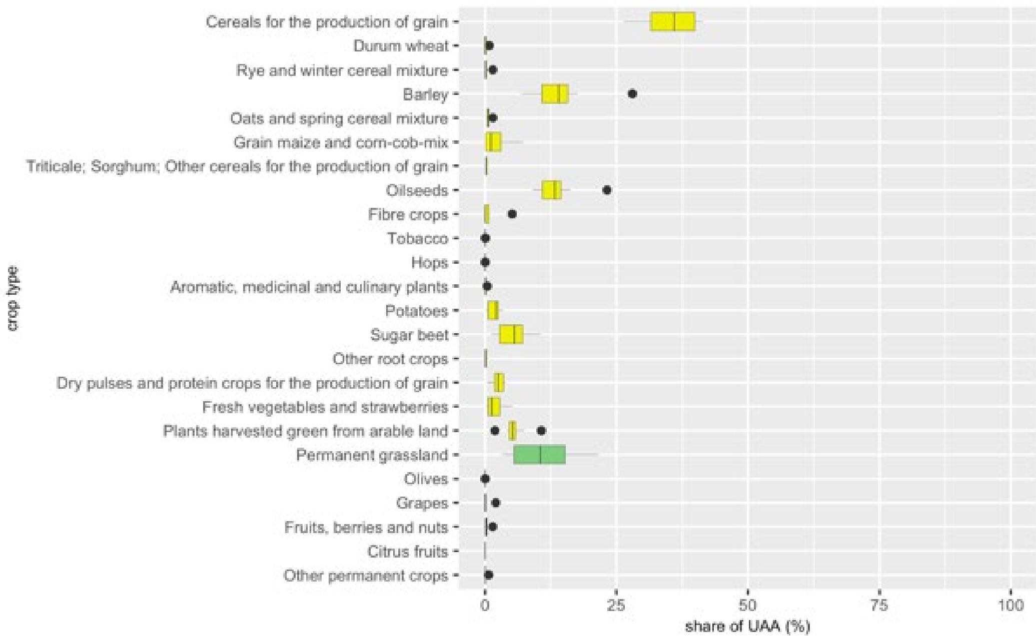
4.2.2 Class 2: Crop landscape of dominant cereals, pulses, industrial, and root crops

Codes of the NUTS2 regions belonging to this class CZ01, DK02, FR10, FR21, FR22, FR23, UKE1, UKE3, UKH1

The agricultural landscape described in Class 2, mainly located in France and the UK, is characterized by a significantly large share of UAA with a median value of 61 %. This can be potentially explained by a high share of the cropping system in which diversity within the system has been categorized as "medium". The British NUTS 2 regions (UKE1, UKE3, UKH1) are geographically located in the east of the country, where it is typically drier and therefore tend to be mainly shaped by the cropping system (Department for Environment Food & Rural Affairs, 2018). The French regions are also situated in the north-east of the country where similarly to the UK mainly the cropping system can be found (Ministère de l'Agriculture et de l'Alimentation, 2021; Moncoulon et al., 2022).

In comparison to other classified agricultural landscapes, Class 2 describes landscapes dominated by cropping activities with significant high shares of cereals (52 %) (e.g., cereals for the production of grain and barley), dry pulses and protein crops (3 %), diverse root crops (7 %) and industrial crops (7 %) (e.g., rape and turnip rape seed, oilseeds) shown in Figure 8. Although livestock is present in Class 2, this agricultural landscape class can be described as a rather extensive system regarding their utilized agricultural area (Figure 9) since shares are comparatively low.

Figure 8 Class 2: Crop distribution (in the share of UAA (%))



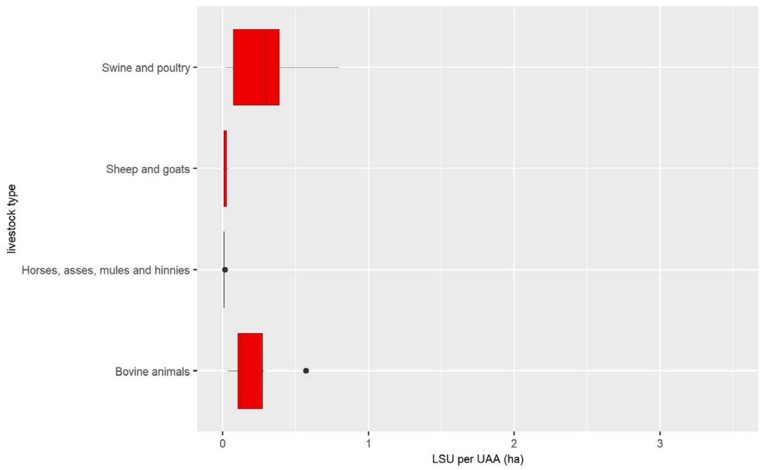


Figure 9 Class 2: Livestock distribution (in LSU per UAA (ha))

4.2.3 Class 3: *Mixed* livestock system of dominant granivores, and horses

Codes of the NUTS2 regions belonging to this class AT22, FR42, FR61, HR04, ITC1, ITC4, ITH3, ITH4, RO11, RO21, RO42, SI01

Class 3 covers twelve regions in one agricultural landscape class with a share of 39 % UAA. Thereby, only regions shaped and influenced by mountainous regions are included: The Alpine region is represented by the North Italian NUTS (ITC1, ITC4, ITH3, ITH4), Slovenia (SI01) as well as Steiermark in Austria (AT22) and Alsace (FR42) in France. The other classified French landscapes are located at the Atlantic and therefore more characterized by the Pyrenees. In addition, the dinaric alps in Croatia (HR04) and the Carpathians shape the three landscapes in the east, west and northern regions in Romania (RO11, RO21, RO42). The landscapes are furthermore impacted by large rivers such as Po and Rhone.

At the core, the class is characterized by a “high” diversity and moderate intensity in the livestock system with granivores (swine: 0.21 LSU/ha; poultry 0.121 LSU/ha) and horses (0.02 LSU/ha) (Figure 10). In contrast, share of the cropping system show a wide variance in each landscape cropping system, hence main common ground in this agricultural landscape class is the livestock system. However, some specific permanent crops like fruits, berries, nuts, and grapes have a comparatively high share which is included in the additional cropping system category. Furthermore, grain maize and corn-cob mix take over a comparatively high share. The cropping system, in fact, reflects the geographic situation of Class 3 where the agricultural landscape is described at a transition between mountainous and lowland regions where also permanent cropping or corn is cultivated besides animal husbandry (Figure 11).

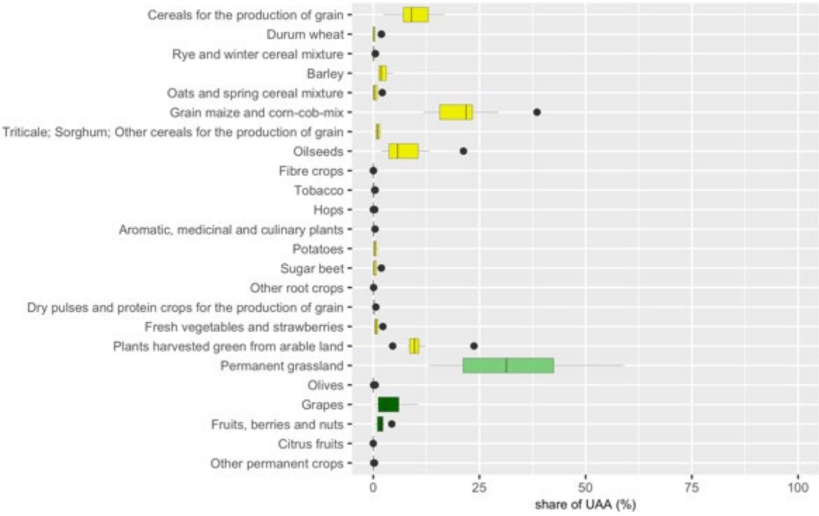


Figure 10 Class 3: Crop distribution (in the share of UAA (%))

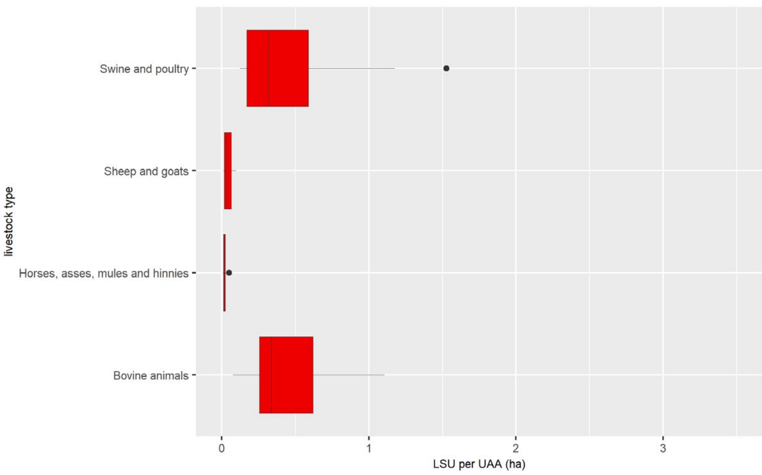


Figure 11 Class 3: Livestock distribution (in LSU per UAA (ha))

4.2.4 Class 4: *Mixed* cropping system of dominant root crops, and vegetables with an extensive bovine livestock system

Codes of the NUTS2 regions belonging to this class : BE10, BE31, BE32, BE33, FR30, NL34

Codes of the NUTS2 regions belonging to this class Class 4 contains a median share of 46 % UAA which comprises mostly Belgian regions complemented by two bordering Dutch and French regions. These landscapes include regions that are highly peri-urban and mostly lowland. Furthermore, the class is significantly shaped by a high diversity in the cropping system (Figure 12). Root crops cover the highest share of UAA with 16 % (mainly potatoes and sugar beet) followed by fresh vegetables and strawberries with 4 %. Additionally, cereals to produce grain and industrial crops, such as fibre and some other industrial crops, are cultivated in this agricultural landscape class. Besides that, the livestock system is extensively focusing on bovine animals (0.58 LSU/ha). (Figure 13)

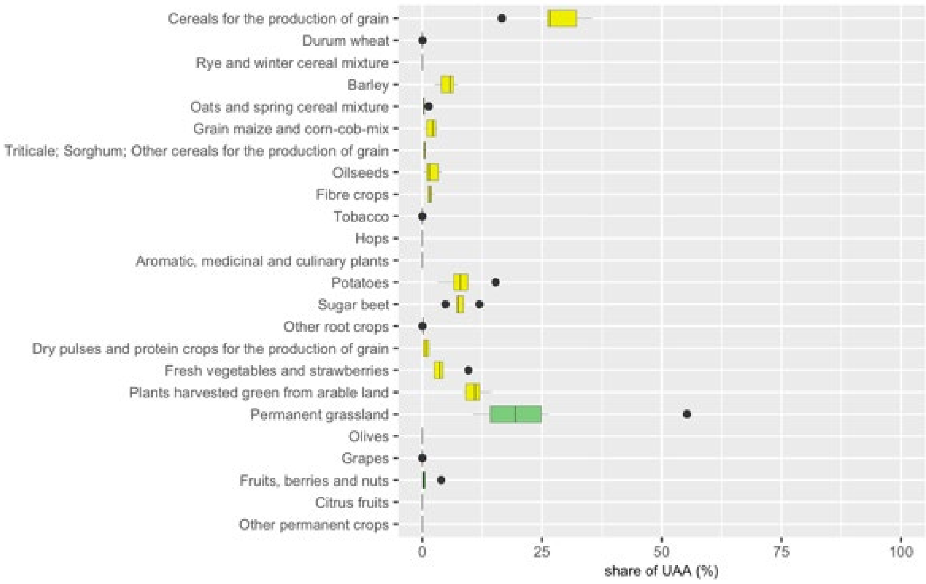


Figure 12 Class 4: Crop distribution (in the share of UAA (%))

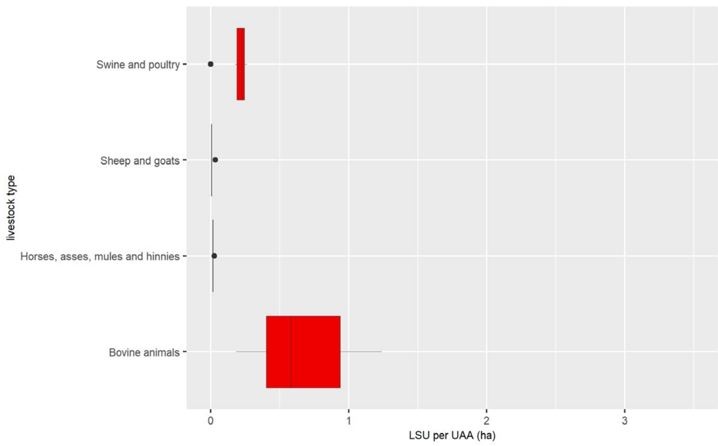


Figure 13 Class 4: Livestock distribution (in LSU per UAA (ha))

4.2.5 Class 5: Cropping system of dominant root crops, vegetables, and grasses with an intensive livestock system of dominant granivores, bovine, goats, and horses

Codes of the NUTS2 regions belonging to this class BE22, BE23, BE24, BE25, MT00, NL11, NL13, NL23, NL32, NL33, NL42

Class 5 consists of Dutch and Belgium regions and remarkably, Malta (MT00), rather to be considered as outlier. The median of the share of UAA is 44 % which positioned Class 5 around the average share of UAA. The intensive *mixed* livestock system shapes (Figure 15) Class 5 with significant high livestock units per area (median swine cover of 0.44, poultry 0.412, bovine 1.1, and horses (et al.) 0.033 LSU/ha). The livestock system is complemented by comparatively significant high shares of root crops (12 %) (predominantly potatoes and sugar beet), fresh vegetables (7 %) and significant high shares of plants harvested green with 22 %.[4] (Figure 14)

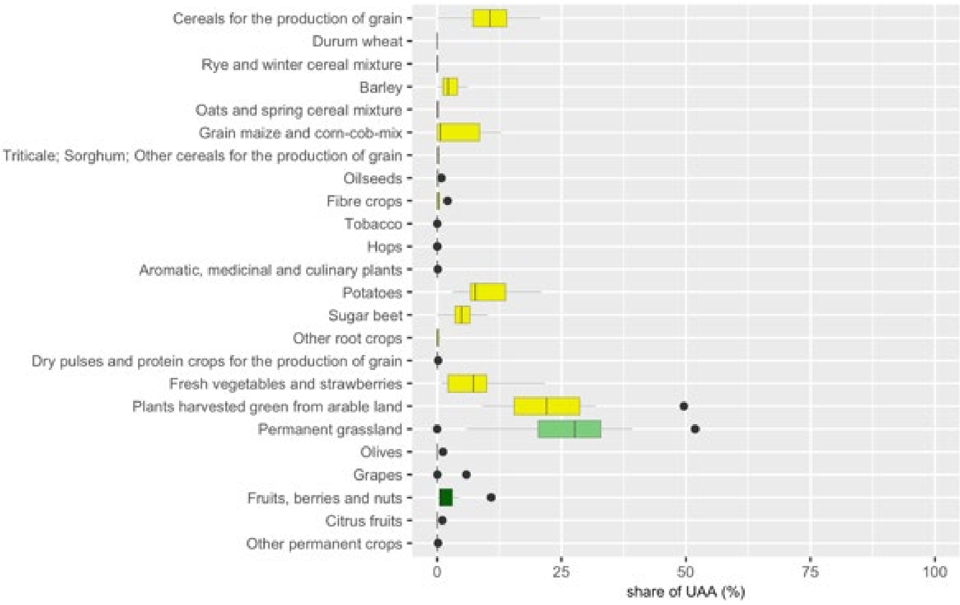


Figure 14 Class 5: Crop distribution (in the share of UAA (%))

[4] According to the agricultural situation in Belgium and the Netherlands it can be assumed that greenhouses have a great structural impact on this agricultural landscape which will not be assessed at this point but could be relevant for further analysis.

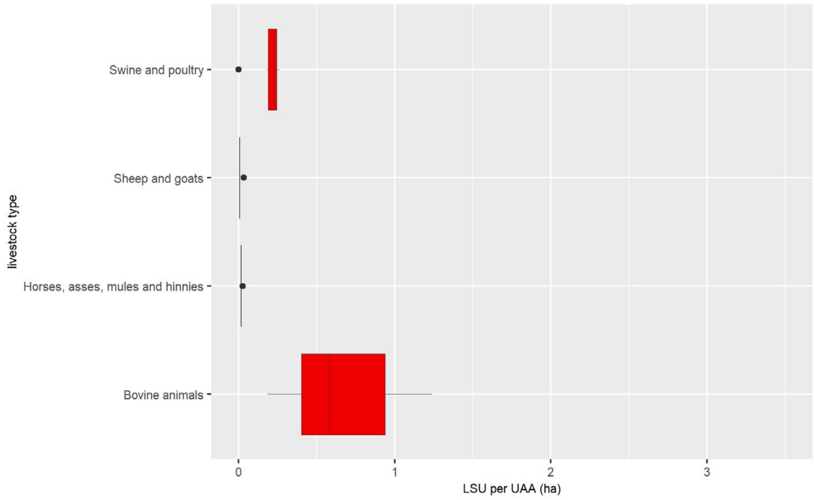


Figure 15 Class 5: Livestock distribution (in LSU per UAA (ha))

4.2.6 Class 6: Bovine livestock system

Codes of the NUTS2 regions belonging to this class AT31, BE35, CZ03, CZ05, CZ08, DE1, DE2, DE7, DE9, DEA, DEB, DEC, DEF, EL13, ES22, ES24, ES30, FI20, FR25, FR26, FR41, FR43, FR51, FR52, FR62, FR63, FR71, FR72, ITH5, LU00, LV00, PL21, PL32, SE21, SK03, SK04, UKK1

As the class summarizes and describes the greatest number of landscapes across Europe, Class 6 has an average UAA of 44 %. Following areas are included in this Class: Upper Austria (AT31); Former West Germany (DE1, DE2, DE7, DE9, DEA, DEB, DEC, DEF) and almost all French landscapes except for the Mediterranean region, parts of the Atlantic coast and the northeast (FI20, FR25, FR26, FR41, FR43, FR51, FR52, FR62, FR63, FR71, FR72). Besides the Central European regions there are also other landscapes that are represented in this class: Middle and northwestern region in Spain (including Madrid) (ES22, ES24, ES30); Western Macedonia (EL13); Emilia-Romagna, Northern region of Italy (ITH5); Luxemburg (LU00) and Lithuania (LV00); South of Poland (PL21, PL32); Southern region in Sweden (SE21) and the Finish Island Aland (FI20); Central and Eastern Slovakia (SK03, SK04) and the Western UK region (UKK1).

The bovine livestock system is the main characterizing element in this class, whereby it is not classified as neither intensive nor extensive system. Apart from that, Class 6 is not characterized by a significantly high value in any of the included crop-tree types of the cropping system due to a high variance in each crop-tree type (Figure 16). Nevertheless, according to the diversity indicator for the cropping system, the described agricultural landscape is rather "low" *mixed*, *i.e.*, not diverse in the cropping system. Similarly, the livestock system is classified as "low" *mixed*. Even though different crop-tree types are cultivated in this agricultural landscape, their total share does not exceed the defined quartile thresholds, hence, is not considered in the final class label. In the additional cropping system cereals (such as rye, winter cereal mixtures, barley, grain maize and corn-cob-mix, triticale, sorghum, and other cereals) with 33 % and permanent grasslands with 39 % are classified (Figure 17)

This reflects the complexity of Class 6, which is unanimously characterized by cattle in the livestock system, while the individual NUTS 2 regions differing considerable with regards to other livestock animals in the livestock system or crop-tree types in the cropping system. Thus, the specification on bovine animals mainly distinguishes the agricultural landscape class from the other classes.

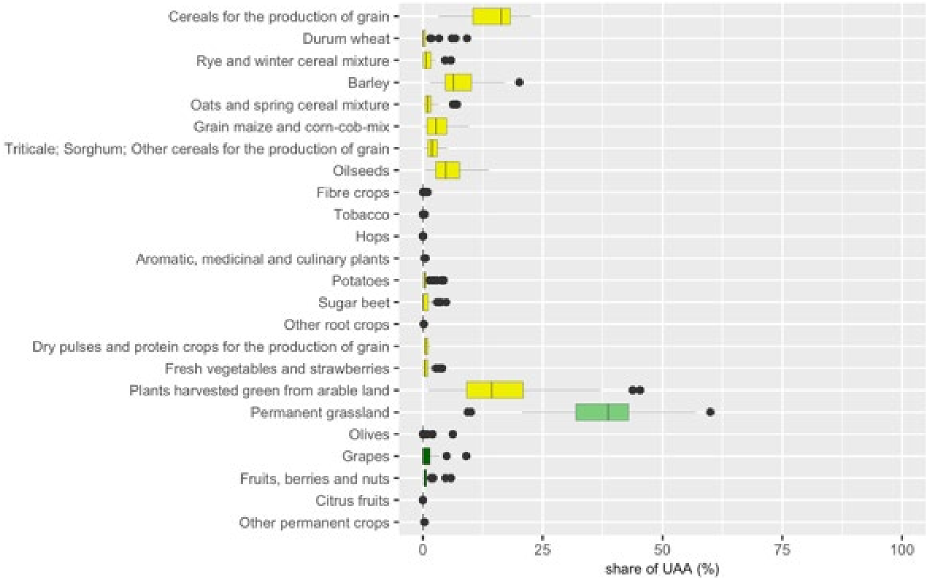


Figure 16 Class 6: Crop distribution (in the share of UAA (%))

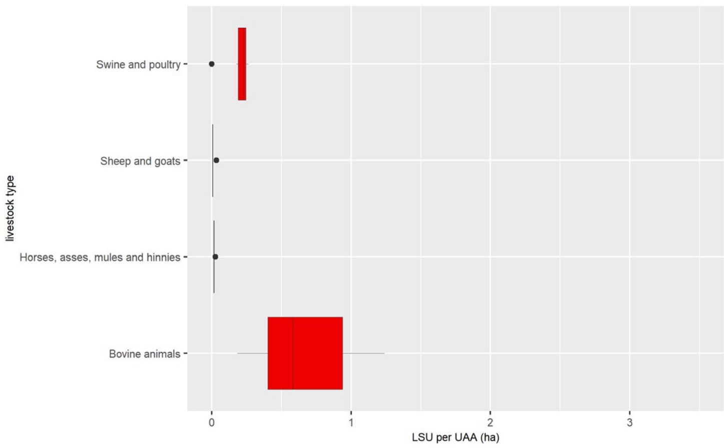


Figure 17 Class 6: Livestock distribution (in LSU per UAA (ha))

4.2.7 Class 7: *Mixed* farming system of dominant cereals, and industrial crops in the cropping system with a dominant poultry livestock system

Codes of the NUTS2 regions belonging to this class AT11, BG31, BG32, BG33, BG34, FR53, HU10, HU21, HU22, HU23, HU31, HU32, HU33, RO22, RO31, RO32, RO41, SK01, SK02

In Class 7, various European landscapes are included (third largest class considering inclusion of different regions) that, in turn, use about half of their area for the agricultural production. Noteworthy, agricultural landscapes include and describe various geographical regions from Central to Eastern Europe, in particular Belgium, Hungary, and Romania. Thereby, these are grouped as *mixed* farming system where the livestock system is defined by "high" diversity and the cropping by "medium". Hence, the livestock system is determined by a variety of different schemes, while these do not fulfil thresholds of being classified as intensive or mentioned in the overview, i.e., in the final label. However, poultry mainly shapes the livestock system of Class 7 agricultural landscape (Figure 19).

The “medium” diversity in the cropping system is reflected in a rather low variety of dominant and additional crop and tree types since industrial crops (mainly tobacco and oilseeds) cover a significantly high ratio of 9 % and cereals 50 % of UAA (e.g., cereals for the production of grain, durum wheat, grain maize, and corn-cob-mix) (Figure 18).

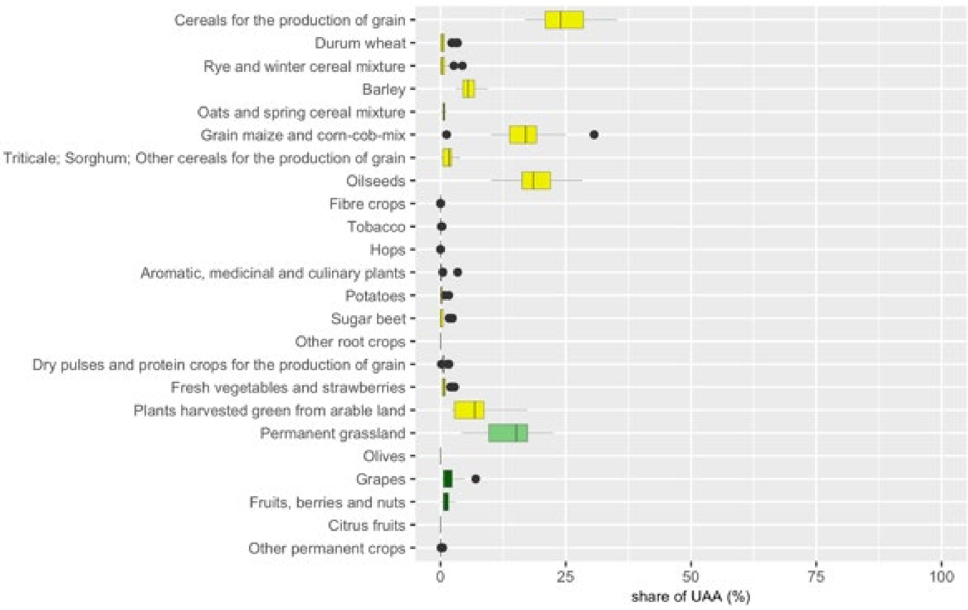


Figure 18 Class 7: Crop distribution (in the share of UAA (%))

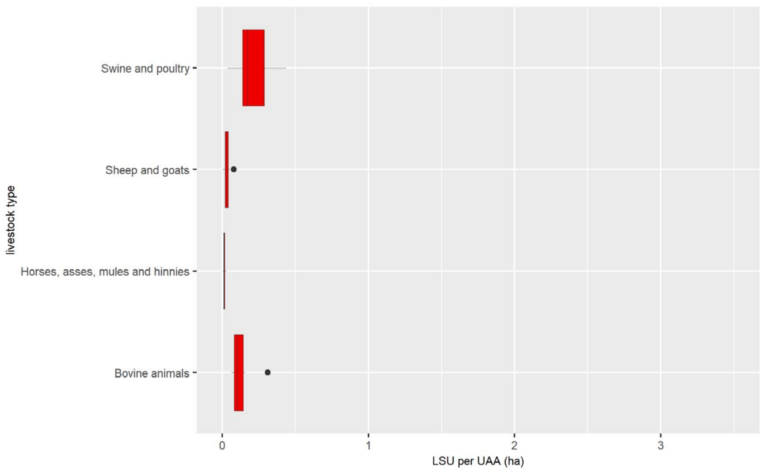


Figure 19 Class 7: Livestock distribution (in LSU per UAA (ha))

4.2.8 Class 8: Cropping system of permanent grassland with a bovine livestock system

Codes of the NUTS2 regions belonging to this class AT21, AT32, AT33, AT34, BE34, BG41, EL21, EL42, ES11, ES12, ES43, FR83, HR03, IE01, ITC2 ITG2, ITH1, ITH2, PT18, PT20, RO12, SI02, UKD1, UKM3, UKM6, UKN0

As second largest class, Class 8 covers 26 landscapes distributed throughout Europe (from the British Isles, Portugal, Italy, Greek and Romania) with a median value of 41 % of UAA. This class shows the highest value of permanent grasslands accompanied with a share of 82 % of bovine in the livestock system (0.5 LSU/ha) (

Figure 20, Figure 21). Astoundingly, triticale, sorghum, and other cereals show a high share, while generally, cereals indicate the smallest overall share with 3 %.

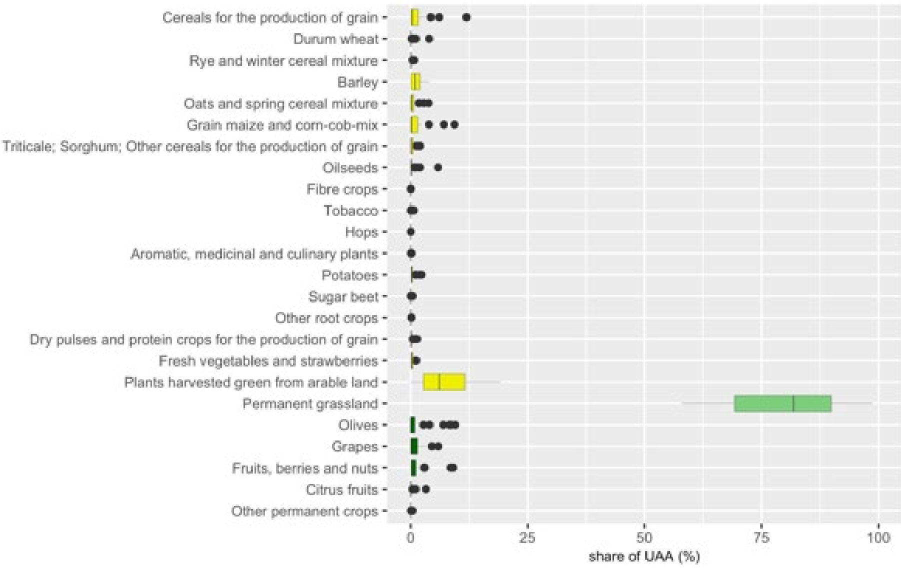


Figure 20 Class 8: Crop distribution (in the share of UAA (%))

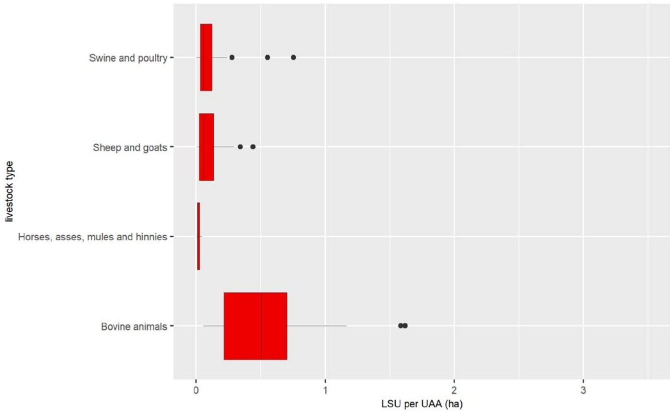


Figure 21 Class 8: Livestock distribution (in LSU per UAA (ha))

4.2.9 Class 9: *Mixed* farming system of dominant industrial, and permanent crops in the cropping system with a dominant sheep livestock system

Codes of the NUTS2 regions belonging to this class BG42, EL11, EL12, ITF3, ITI2

Class 9 comprises a small number of NUTS 2 landscapes (five in total), which have an exceptional mix of Mediterranean regions (two each in Italy and Greece) and the southern-central Bulgarian region "Yuzhen tsentralen". The described agricultural landscape contains a rather low share of UAA with 36 % where the *mixed* cropping system is dominantly characterized by industrial crops such as tobacco, oilseeds, and aromatic, medicinal and culinary plants as well as by permanent crops such as fruits, berries and nuts, olives, and vineyards. 8.5% of UAA in the agricultural landscape is covered by systems of industrial crops which is significantly high. In contrast to Class 10 and 14, permanent crops feature a rather low share of UAA that signals a lower significance of permanent crops in the crop activities. The livestock system is identified as "high" in diversity in which sheep with 0.053 LSU/ha are comparatively dominant (Figure 22, Figure 23).

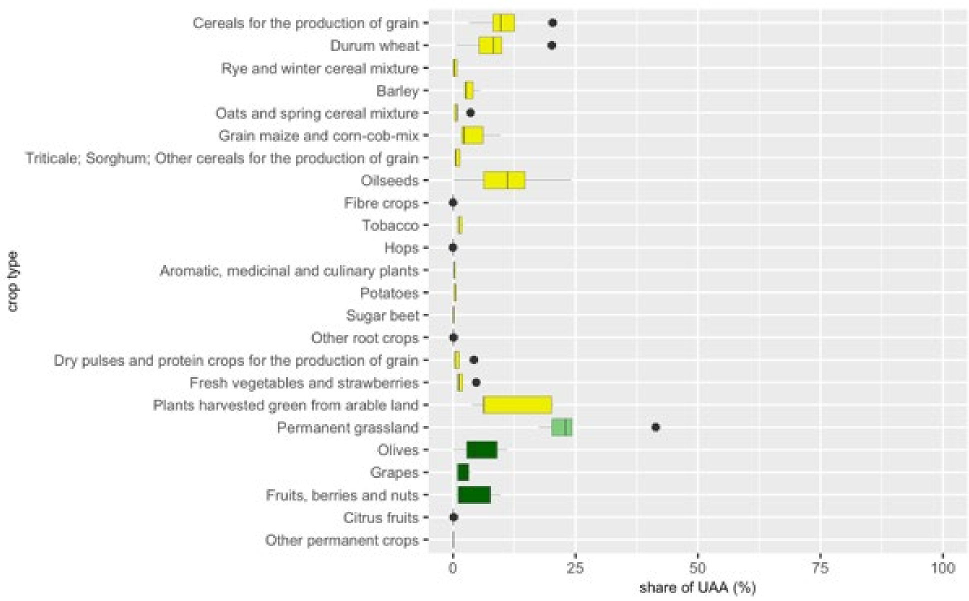


Figure 22 : Class 9: Crop distribution (in the share of UAA (%))

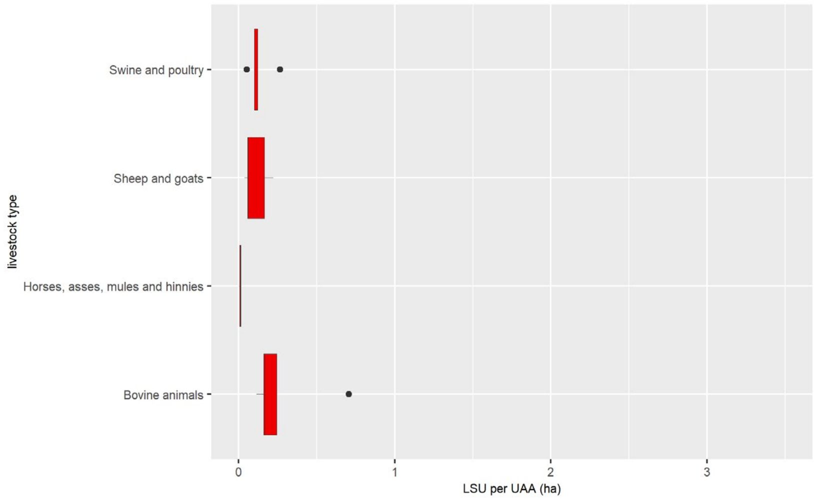


Figure 23 Class 9: Livestock distribution (in LSU per UAA (ha))

4.2.10 Class 10: *Mixed* farming system of dominant permanent crops in the cropping system with a dominant sheep, and goat livestock system

Codes of the NUTS2 regions belonging to this class CY00, EL14, ES23, ES42, ES51, ES52, ES62, FR81, FR82, ITF1, ITI1, ITI4, PT11, PT15, PT16, PT17

Class 10 is characterized by a comparatively low UAA share of 31 %. This, in turn, covers a large proportion of NUTS 2 regions, particularly in the southern coastal regions whose landscapes appear to correspond to, namely Mediterranean regions in Cyprus, Greece, Spain, France, Italy and Portugal. This *mixed* farming system describes agricultural landscapes where the livestock system is classified for the diversity index as “high” and the cropping system as “medium”. Thereby, in line with Mediterranean landscapes, a significantly high share of permanent crops (with 24% second highest value in comparison to the other classes) with fruits, berries and nuts, olives, vineyards, and other permanent crops shape this agricultural landscape (Figure 24). The *mixed* livestock system is mainly shaped by sheep and goats with 0.06 and 0.009 LSU/ha, respectively (Figure 25), however Class 14 encompasses an even higher share for both livestock species. Beyond that, characterization of this livestock system follows agronomic expectations where permanent cropping systems such as olive or vineyard landscapes are accompanied by sheep and goat’s husbandry (de Porras, 2020).

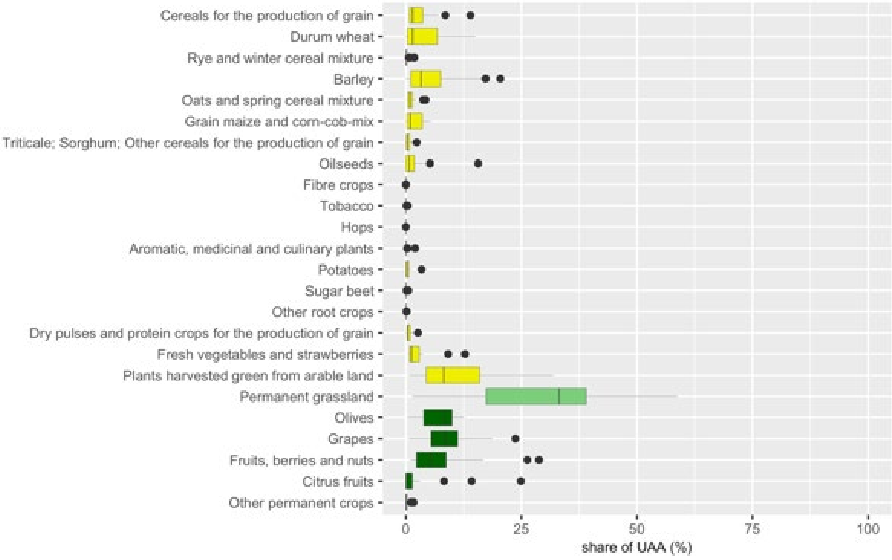


Figure 24 Class 10: Crop distribution (in the share of UAA (%))

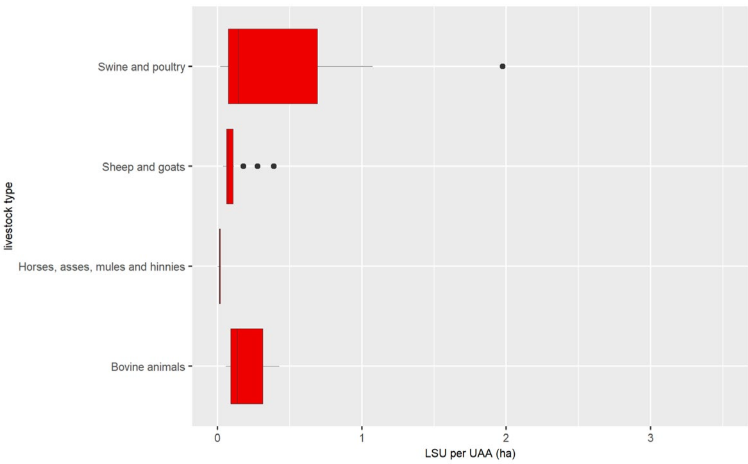


Figure 25 Class 10: Livestock distribution (in LSU per UAA (ha))

4.2.11 Class 11: Cropping system of permanent grassland with a dominant bovine and horses (et al.) livestock system

Codes of the NUTS2 regions belonging to this class DE5, DE6, ES13, ES21, SE11, UKD3

Class 11 mostly represents peri-urban areas such as Stockholm (SE11), Hamburg (DE6), Bremen (DE5) or Greater Manchester (UKD3) and harbor-orientated regions such as Cantabria (ES13) and Basque Community (ES21). This might explain the significantly low share of UAA with 25 %. The class is characterized by the combination of high permanent grassland values (68 %) and livestock systems with bovine (0.49 LSU/ha) and significant high horses (et al.) shares of 0.09 LSU/ha which assemble the livestock and cropping system that are both classified with “low” diversity (Figure 26, Figure 27). This composition is noteworthy since urban areas (assuming historically older cities) emerged and developed around fertile regions and arable land. However, this agricultural landscape describes an exception, where urban areas primarily emerged due to water trade routes and their strategic position for harbors, while grassland, grasses, some permanent cropping systems combined with bovine and horse livestock systems were – agronomically practical – established.

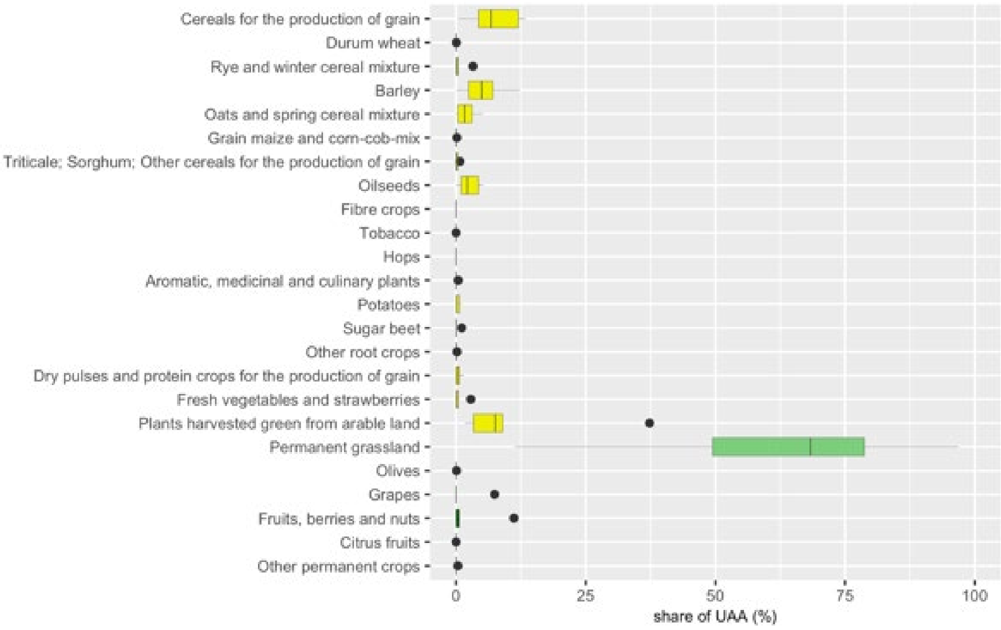


Figure 26 Class 11: Crop distribution (in the share of UAA (%))

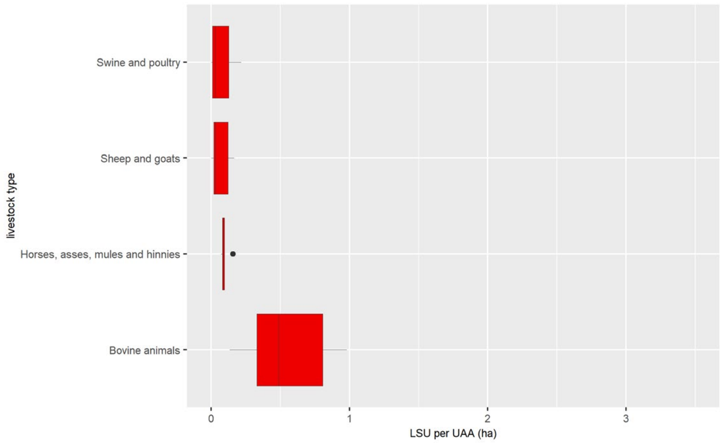


Figure 27 Class 11: Livestock distribution (in LSU per UAA (ha))

4.2.12 Class 12: *Mixed* cropping system of dominant cereals, and grasses with an intensive dominant swine, and horses (et al.) livestock system

Codes of the NUTS2 regions belonging to this class DK01, DK03, DK04, DK05, ES53

The Danish-dominated Class 12 describes an agricultural landscape that is shaped above-average by a large share of agricultural area (52 % UAA). Surprisingly, the agricultural landscape marked by low variance (particularly in the cropping system) and thereby indicated a rather homogeneous group, also characterizes the Balearic Islands (ES53). This can be explained by a historic change in Balearic agriculture where touristic activities put pressure on agricultural areas and pushed, exemplarily, cropping systems and dairy systems towards intensive pig and cash crop cropping systems (Murray et al., 2019).

Comparatively to the other classes, cereal share of 54% is significantly high, while generally this agricultural landscape can be described by a *mixed* cropping system. Apart from that, some other permanent crops shape the landscape, which is likely to be due to the Balearic Islands. The high shares of grasses (24%) can be directly linked to the intensive livestock system mainly swine and horses (et al.), which in turn allow the livestock system to be labeled as “low” in diversity. Following Class 18, Class 12 represents the second highest share of swine systems with 1.04 LSU/ha. (Figure 28, Figure 29)

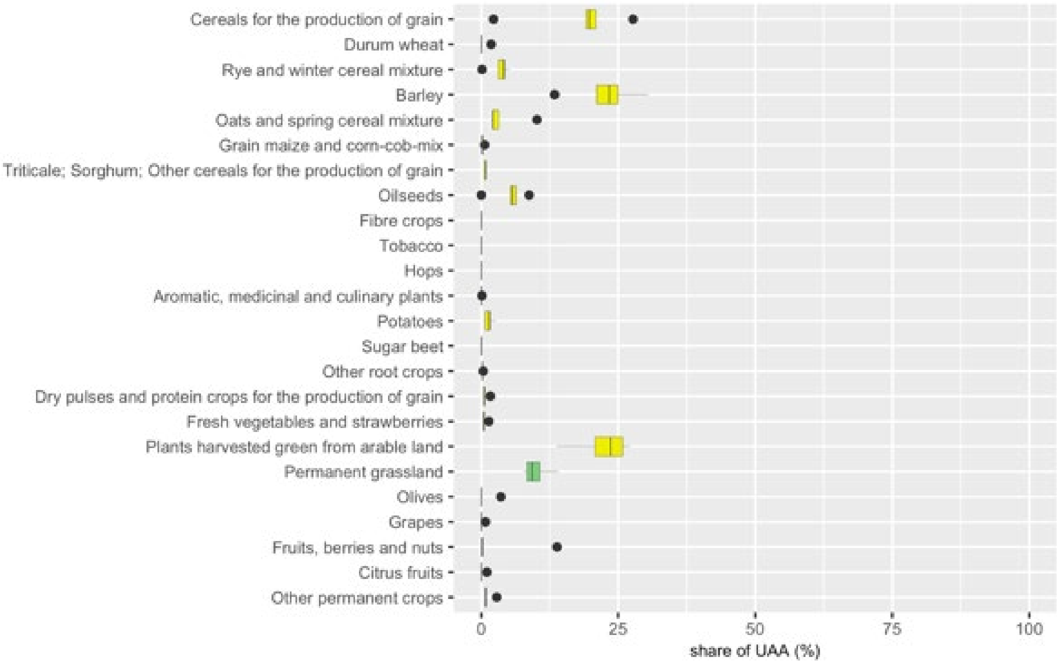


Figure 28 Class 12: Crop distribution (in the share of UAA (%))

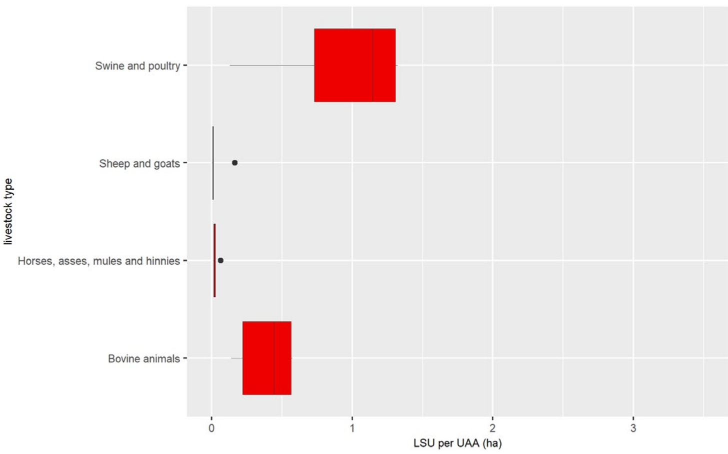


Figure 29 Class 12: Livestock distribution (in LSU per UAA (ha))

4.2.13 Class 13: *Mixed* farming system of dominant industrial crops, and pulses in the cropping system with an intensive dominant sheep and horses (et al.) livestock system

Codes of the NUTS2 regions belonging to this class EE00, ES41, LT00, UKD7, UKE3, UKF2, UKG3, UKH2, UKH3, UKJ1, UKJ3, UKJ4

The mainly UK driven Class 13 covers 12 landscapes that contain a median value of 48% UAA. In addition, Estonia (EE00), Lithuania (LT00) and Castile and León, a Spanish region in the Northwest of Central Spain are represented as one agricultural landscape in this class.

The class labeled as *mixed* farming system where the livestock system is classified as “high” in its diversity and intensive in its intensity, while the cropping system is classified as “medium” in the diversity index. Precisely, the livestock system is dominantly shaped by sheep (0.079 LSU/ha) and horses (et al.) (0.021 LSU/ha). The cropping system focuses on where pulses have by far the highest significant value of 4% share complemented by industrial seeds (5.5%) such as oilseeds. Apart from that, some cereals such as barley, oats and spring cereals mixture are also cultivated in the described agricultural landscape. For UK, this class laid the focus on the cropping system and on its diversity, while other British landscapes are included in Class 17 with permanent grassland.(Figure 30, Figure 31)

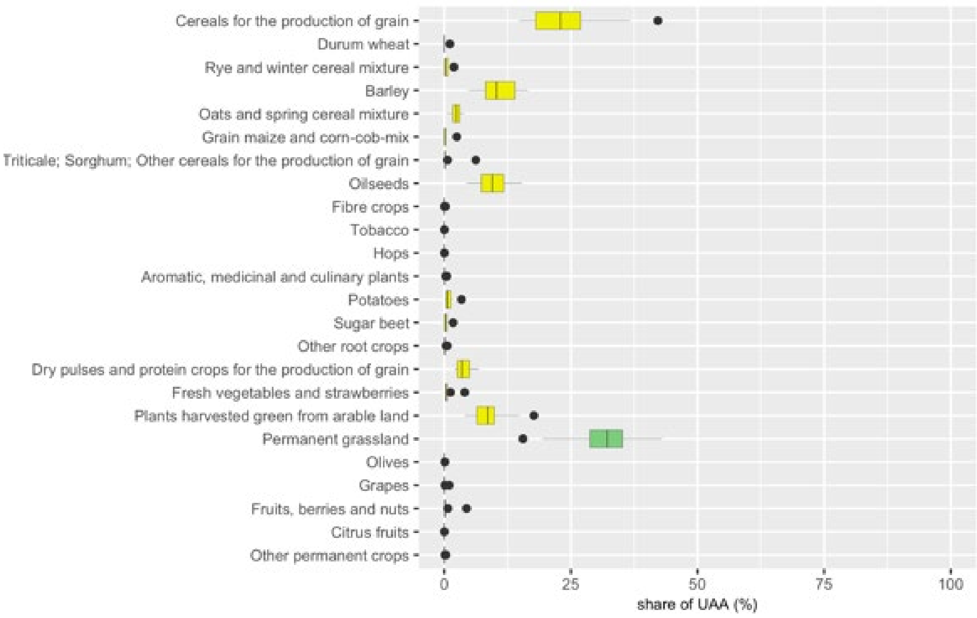


Figure 30 Class 13: Crop distribution (in the share of UAA (%))

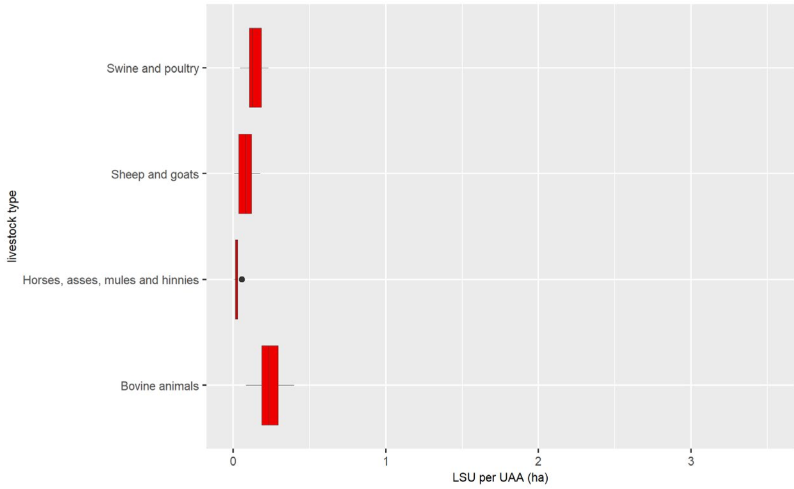


Figure 31 Class 13: Livestock distribution (in LSU per UAA (ha))

4.2.14 Class 14: Cropping system of permanent crops, vegetables, and permanent grassland with a *mixed* livestock system of dominant sheep and goats

Codes of the NUTS2 regions belonging to this class EL22, EL23, EL24, EL25, EL30, EL41, EL43, EL61, ITF6

Class 14 comprises a vast majority of regions from Greece (eight out of nine regions), which are significantly characterized by a *mixed* permanent cropping system (36 %) with olives, vineyards, fruits, berries, nuts, and other permanent crops. In addition, fresh vegetables, and strawberries (1 %) also take a large part as well as permanent grasslands (40 %). The grasslands and the permanent crops seem to be directly related to the sheep and goats in the livestock system (0.127 and 0.076 LSU/ha) which must be referred to as the determining livestock system with significant high shares (Figure 32, Figure 33)

Figure 32 Class 14: Crop distribution (in the share of UAA (%))

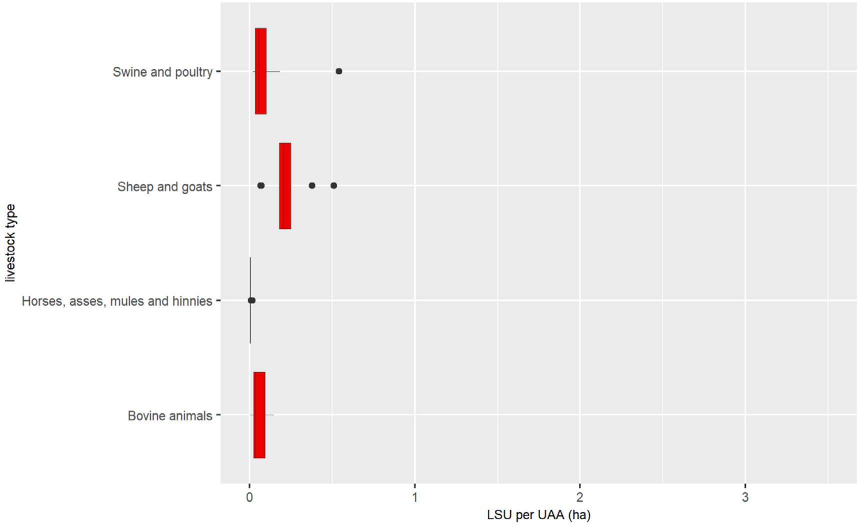


Figure 33 Class 14: Livestock distribution (in LSU per UAA (ha))

4.2.15 Class 15: *Mixed* farming system of dominant cereals, pulses, and grasses in the cropping system with a dominant extensive swine livestock system

Codes of the NUTS2 regions belonging to this class FI19, FI1B, FI1C, SE12, SE23

Class 15 identifies the agricultural landscape in the Scandinavian region (Sweden and Finland), where the significantly smallest share of UAA was found with an average of 17 %. Some Finish and Swedish regions have been previously excluded since the total share of UAA has not reached the minimum requirements to be included in that research. Therefore, even these areas, which were included in the classification still show comparatively smaller shares. Consequently, these landscapes show rather separate elements that are accompanied by agriculture than inversely. This should be noted regarding the further description and the later evaluation.

However, the classified agricultural landscape in this class puts its focus on a *mixed* farming system where the arable cropping system mainly comprises a “high” diversity of different crops, such as cereals (55 %), pulses and protein crops (2 %) and, supplementary, plants harvested green with a large share of 26 % of UAA (Figure 34). While the livestock system is classified as “medium” in its diversity but extensive in intensity where swine found to be the dominant animal in the livestock system (Figure 35). Apart from that, it must be considered that Sweden and Finland might have other animals in its livestock system, but some animal types are not reflected in the EU survey at NUTS 2 level (e.g., reindeers).

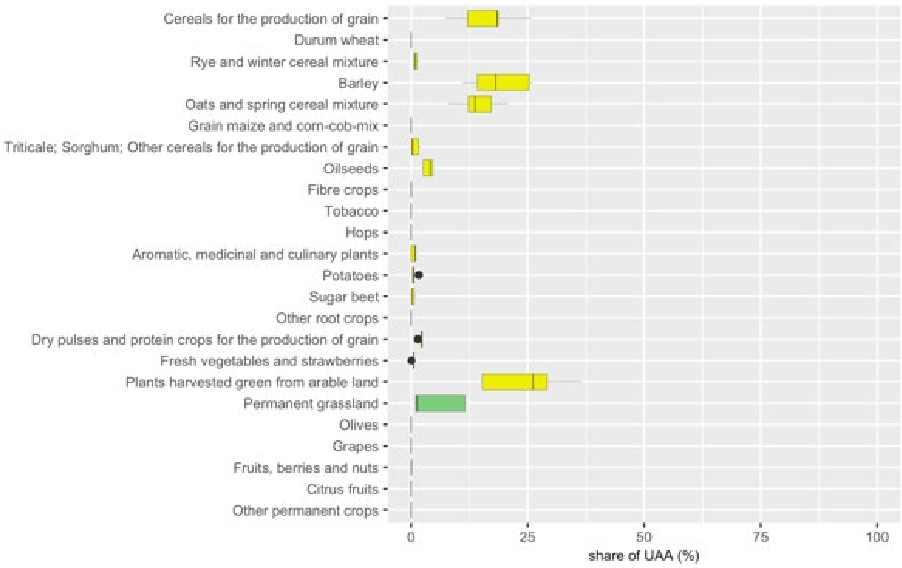


Figure 34 Class 15: Crop distribution (in the share of UAA (%))

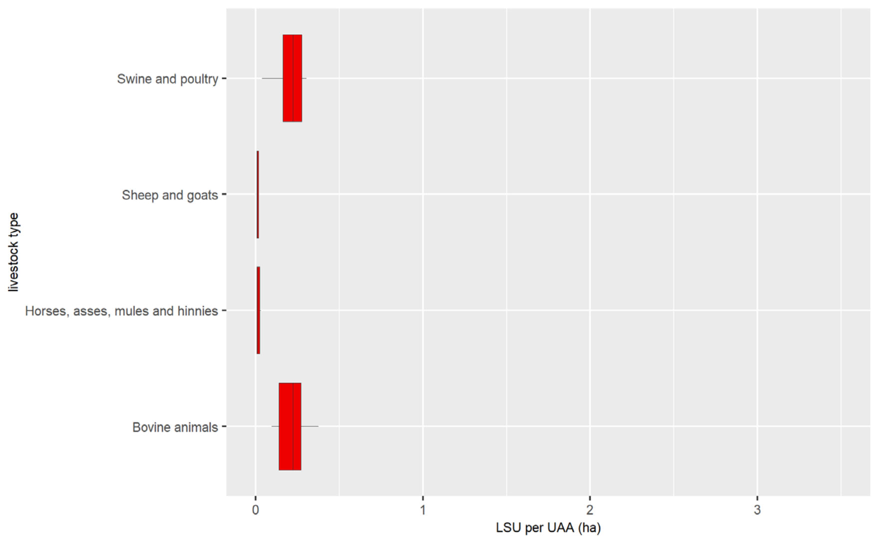


Figure 35 Class 15: Livestock distribution (in LSU per UAA (ha))

4.2.16 Class 16: *Mixed* farming system of dominant vegetables, grasses, and permanent crops in the cropping system

Codes of the NUTS2 regions belonging to this class ITF2, ITF4, ITF5, ITG1, ITI3

Class 16 specifies an agricultural landscape that identifies exclusively NUTS 2 landscapes from Southern Italy, mainly characterized by a *mixed* cropping system. Permanent cropping system mainly shape this class of agricultural landscape with fruits, berries and nuts, olives, grapes, and other permanent crops, albeit, in comparison to Class 9, 10, 14, classes that are also classified by a permanent cropping system, shares are comparatively low (but fulfil the defined requirements of being mentioned as dominant cropping system) (Figure 36). Furthermore, the arable cropping system with dry pulses and protein crops (3 %); fresh vegetables and strawberries (2 %), as well as plants, harvested green (15 %) highly influences the class characteristics. The livestock system is *mixed,* extensive, and no dominant livestock system can be identified. (Figure 37

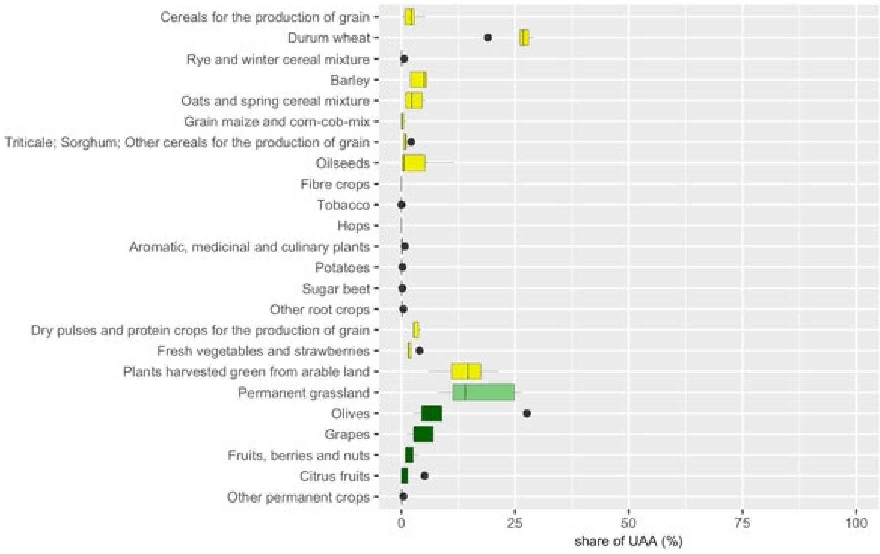


Figure 36 Class 16: Crop distribution (in the share of UAA (%))

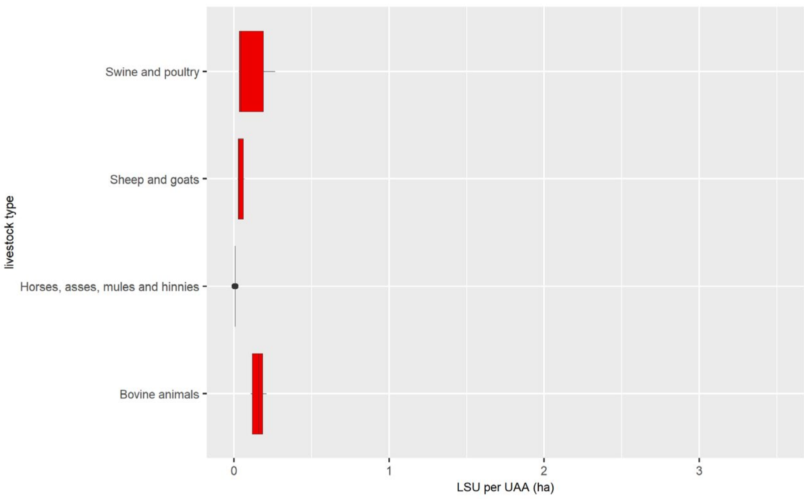


Figure 37 Class 16: Livestock distribution (in LSU per UAA (ha))

4.2.17 Class 17: Cropping system of permanent grassland with an intensive livestock system of dominant sheep and horses (et al.)

Codes of the NUTS2 regions belonging to this class IE02, UKC1, UKC2, UKD4, UKD6, UKE2, UKE4, UKF1, UKG1, UKG2, UKJ2, UKK2, UKK3, UKK4, UKL1, UKL2, UKM2, UKM5

This agricultural landscape encompasses a great part of the British Isles' landscapes and is shaped by it with a significantly high share of UAA (70%) which is prominent for most of the agricultural landscapes in UK and south-eastern parts of Ireland (IE02). Permanent grasslands are widespread and determining aspects for this landscape by covering 63 % of the UAA (Angus et al., 2009), whereas only Class 11 and 8 contain higher shares of grasslands (Figure 38). The diversity index for the cropping system is classified as "low. The grasslands are complemented by grazing of sheep (significant high share of 0.206 LSU/ha) and horses (et al.) in the livestock system, that are in turn categorized as "medium" *mixed* (Figure 39).

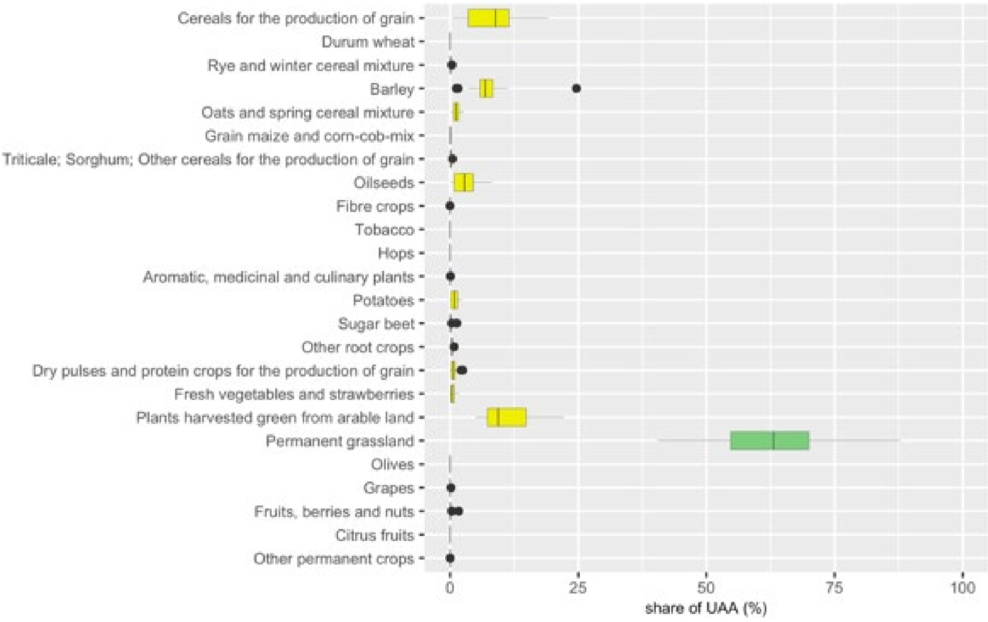


Figure 38 Class 17: Crop distribution (in the share of UAA (%))

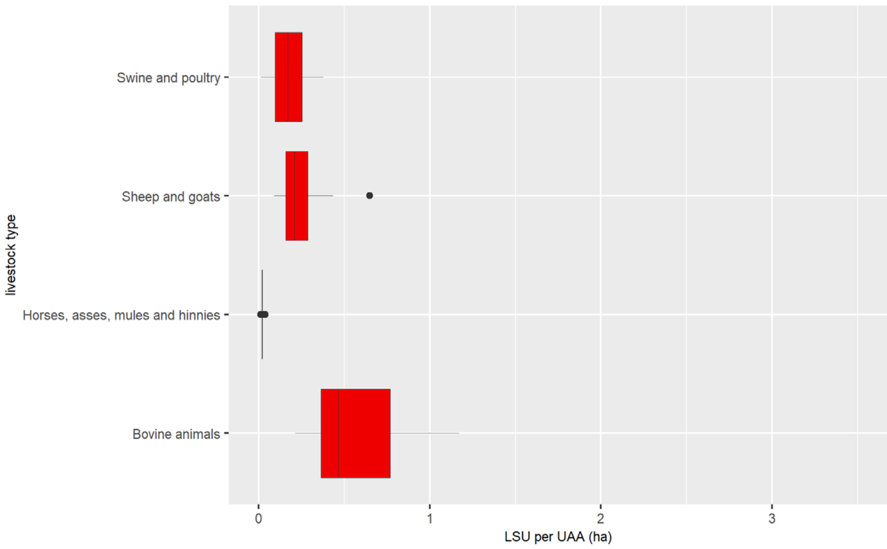


Figure 39 Class 17: Livestock distribution (in LSU per UAA (ha))

4.2.18 Class 18: Cropping system of root crops, grasses, and permanent grassland with an intensive livestock system of dominant bovine, granivores, and horses

Codes of the NUTS2 regions belonging to this class BE21, NL12, NL21, NL22, NL31, NL41

Class 18 has a high informative value for some NUTS2 Dutch regions as five of the six regions are in the Netherlands. The median area of 44 % of UAA is used in particular by an intensive *mixed* livestock system with all considered animal categories and significant high shares of swine and poultries (1.67 and 0.833 LSU/ha), horses (0.06 LSU/ha) and bovine animals (2.23 LSU/ha) (Figure 40). Besides that, some root crops (5%) are also cultivated (Figure 40).

Class 18 covers agricultural landscapes with the highest share of plants harvested green with 32%. Furthermore, the high share of permanent grassland with 57% shows a direct interlinkage to the emphasis on the livestock system and its intensity (Figure 41).

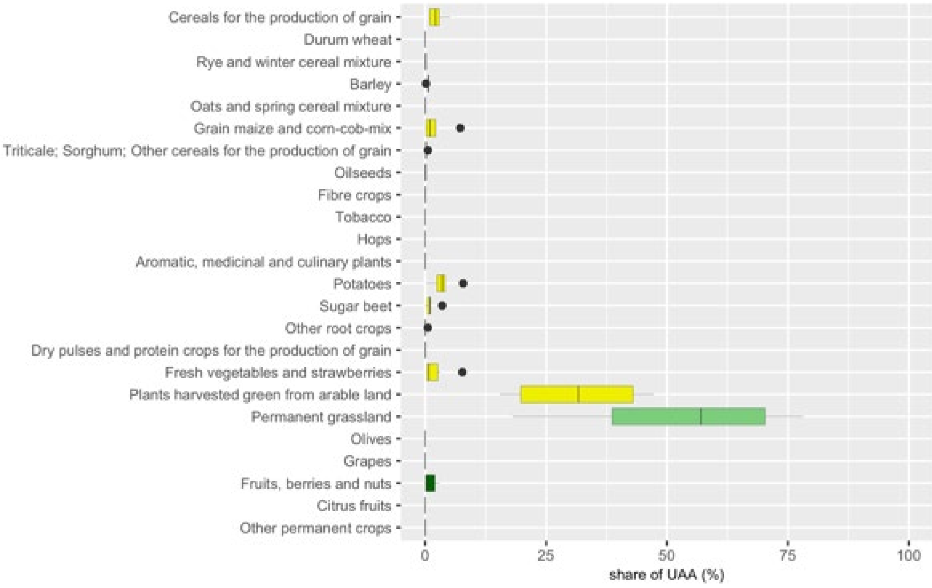


Figure 40 Class 18: Crop distribution (in the share of UAA (%))

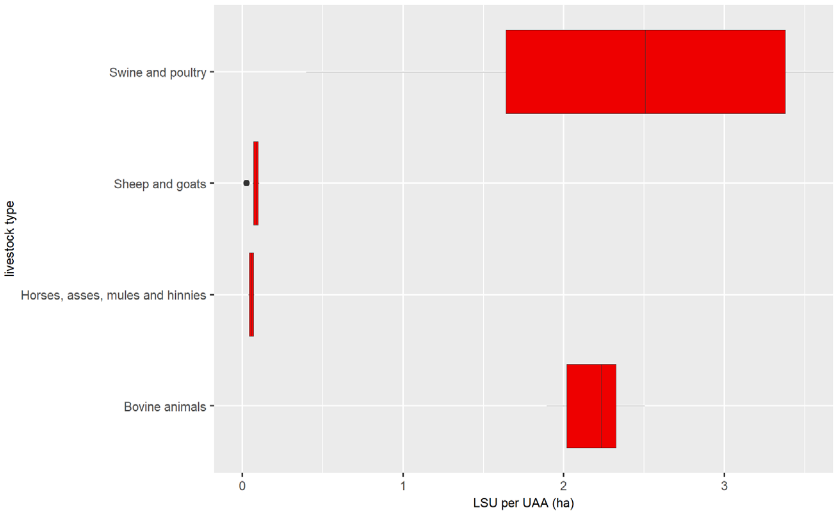


Figure 41 Class 18: Livestock distribution (in LSU per UAA (ha))

4.2.19 Class 19: *Mixed* cropping system of dominant cereals, pulses, and vegetables with a dominant monogastric livestock system

Codes of the NUTS2 regions belonging to this class PL11, PL12, PL22, PL31, PL33, PL34, PL41, PL42, PL43, PL61, PL62, PL63

More than half of Poland's NUTS 2 landscapes are explained in Class 19 (12 out of 17). The median UAA share in this class lies around 46 %. The agricultural landscape is characterized by a combination of an arable cropping system with a significantly high share of different types of cereals (52%) and other crop types such as dry pulses and protein crops (2%), fresh vegetables and strawberries (1%) (Figure 42). Additionally, tobacco, other industrial and other permanent crops, as well as potatoes are cultivated in this landscape. From the livestock system perspective, monogastric livestock categories (with median swine share of 0.13 and poultry 0.128 LSU/ha) take over the highest share while other livestock categories are low in their share (Figure 43).

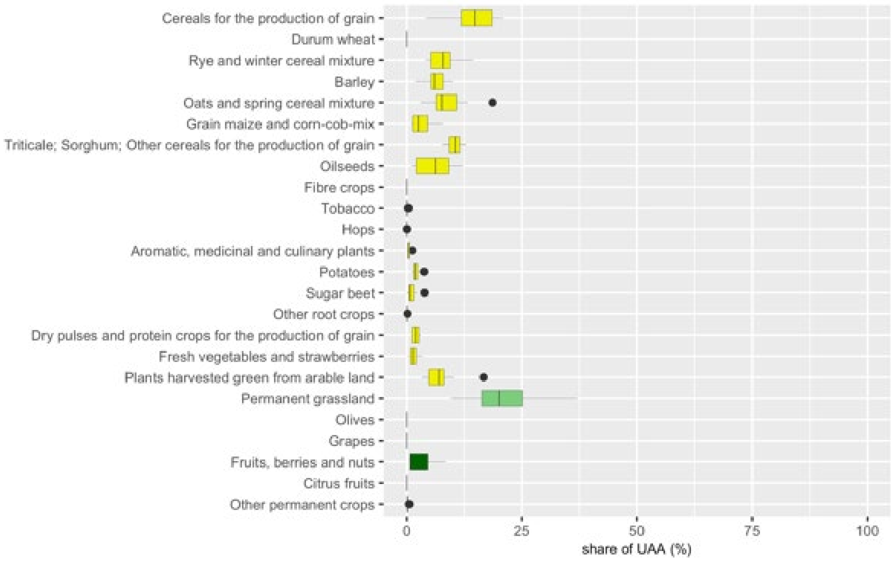


Figure 42 Class 19: Crop distribution (in the share of UAA (%))

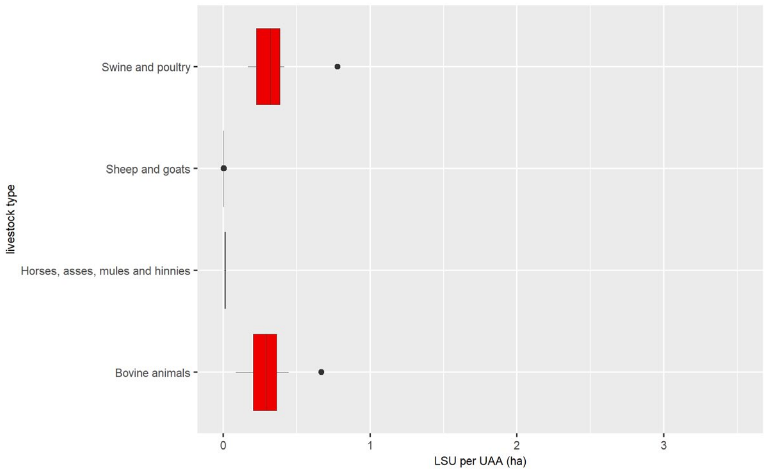


Figure 43 Class 19: Livestock distribution (in LSU per UAA (ha))

4.3 Step 3 : quantifying ESB

For each ESB indicator, a boxplot analysis per agricultural landscape category and classes were made to identify. The boxplot allows to identify if and ESB indicator is significantly different from one landscape category from another, when the boxes do not overlap. This analysis allows to assess between mixed landscapes and ESB provision and identify which ESB indictor is significantly different.

4.3.1 ESB per landscape category

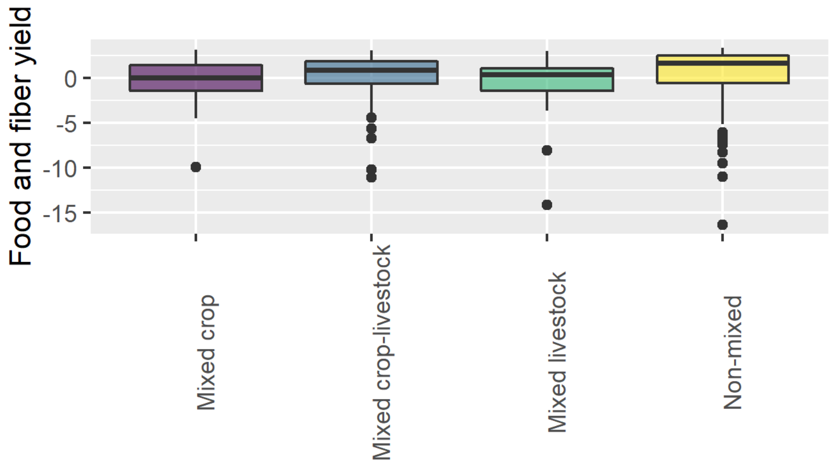


Figure 44 : Provisioning service food and fiber (first PCA loading on the price of crop and milk) per landscape category

In terms of food and fiber provision, non-mixed landscape have the highest median provision, however it is not significantly different from mixed landscapes (Figure 44).

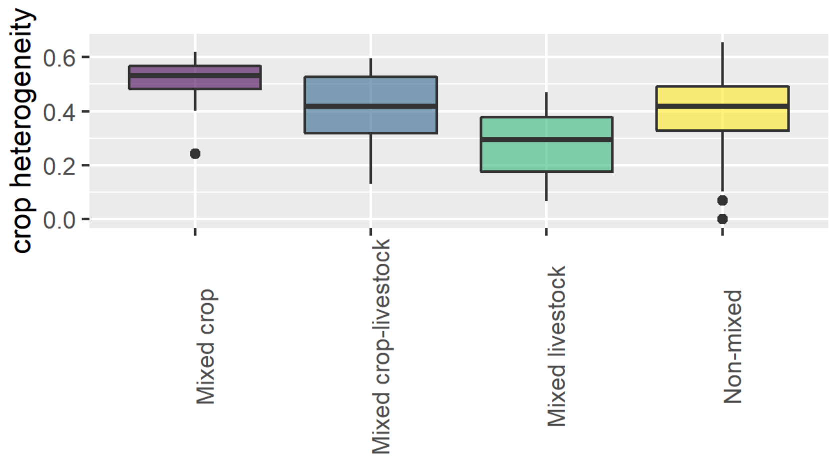


Figure 45 : biodiverisity : crop heterogeneity (SHEI index) per landscape category

Crop heterogeneity is unsurprisingly highest in mixed crop landscape and is significantly higher than in mixed livstock landscape. This is because mixed livestock landcape only marginally produce crops, and crop diversity is not an appropriate metric for biodiversity. There is no significant difference between other classes of landscapes (Figure 45).

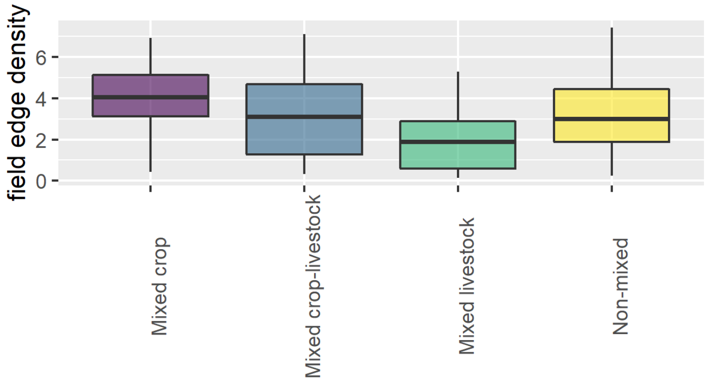


Figure 46 : field edge density (SPLIT) per landscape category

Field edge density is highest in mixed crop landscape and is significantly higher than in mixed livestock landscape, however there is no significant difference between the other landscape categories; Figure 46.

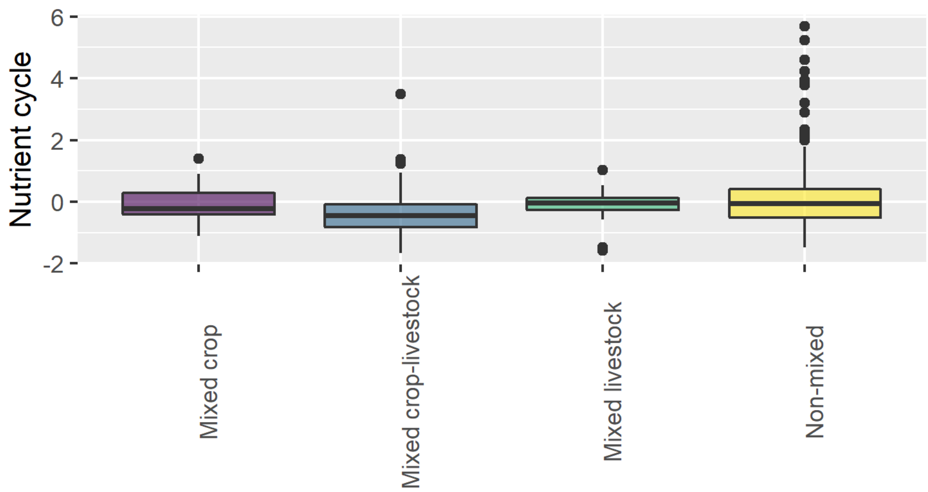


Figure 47 : supporting service : nutrient cycle (first PCA loading on nitrogen and phosphorus balance) per landscape category

No significant difference can be found in terms of nitrogen cycle accross the different landscape categories. Yet at the median mixed crop-livestock landcape have the lowerst balance. Because this balance computation does not account for green manures, these are likely to be the landscapes with the last leaching (Figure 47).

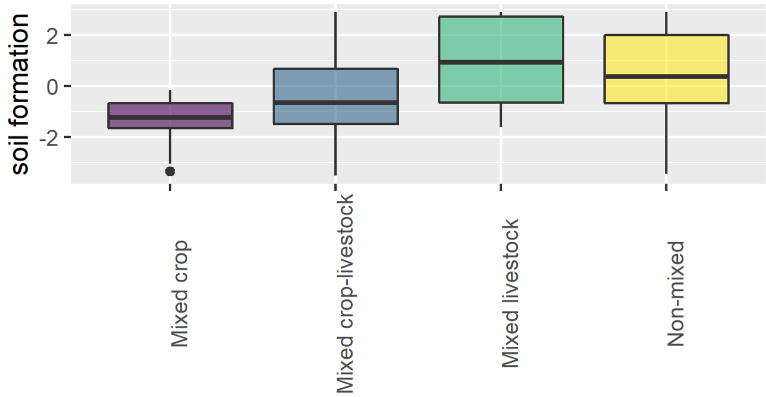


Figure 48 : supporting service soil formation per landscape category

Soil formation is the highest for mixed livestock agricultural landscape though only significantly different from the mixed crop landscape. This can be explained by the fact that livestock dominated landscapes are often those thare are located in mountains with slope, and were reduced tillage and year round cover crops are crititical for erosion control (Figure 48).

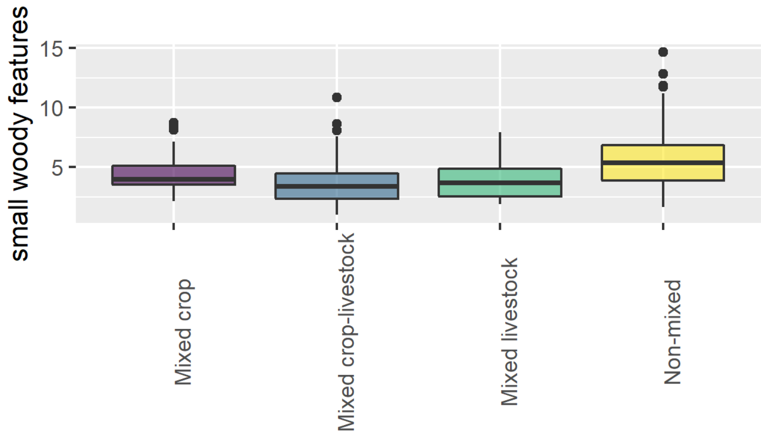


Figure 49 : supporting service small woody feature per per landscape category

Small woody features are surprisingly highest in non-mixed landcape, yet non significantly different from other landscape types. This indicates that this important factor for high biodiversity is (still) present in a number of non-mixed landscapes (Figure 49).

4.3.2 Ecosystem services per landscape class

Part of the heterogenity might got lost in the aggregation to the four landscape categories, this is why this section explores the same ESB indicator within landscape classes.

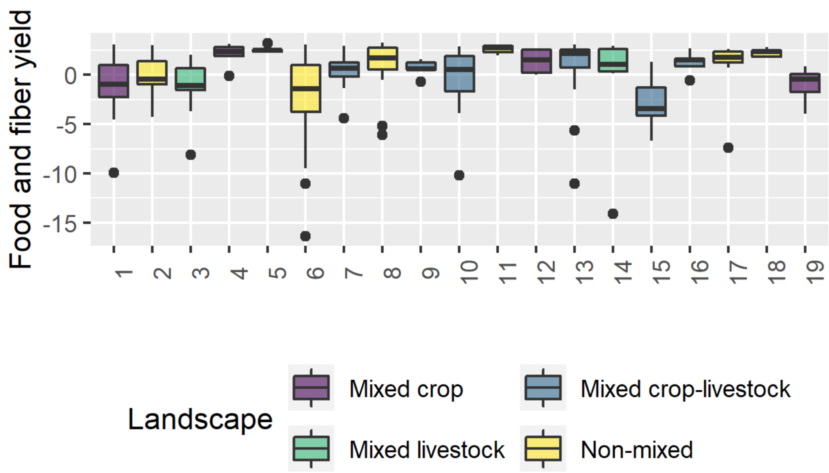


Figure 50 : Provisioning service food and fiber (first PCA loading on crop and milk price) per landscape class

Figure 50 shows that class 15 (*mixed farming system of dominant cereals, pulses, and grasses in the cropping system with a dominant extensive swine livestock system*) found in scadinavia and class 19 (Mixed cropping system of dominant cereals, pulses, and vegetables with a dominant monogastric livestock system) found in Poland are the landscapes with a significantly lowerst provision of food and fiber than most other landscapes.

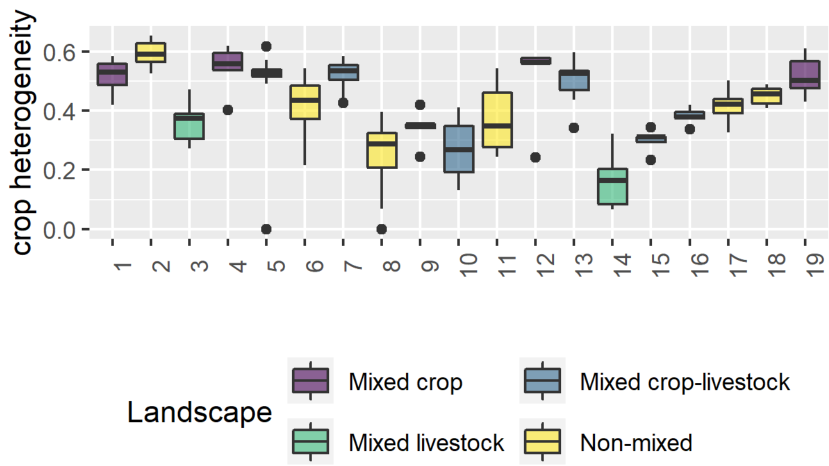


Figure 51 : biodiverisity : crop heterogeneity (SHEI) per per landscape class

Figure 51 shows that landscape class 14, crop of permanent crops, vegetables, and permanent grassland with a mixed livestock of dominant sheep and goats found in the Mediterranian area has the lowest crop diversity and is significantly different from all other landscapes. This is because the landscape is dominated by permanent crops that are not captured by the cropmap used for the crop heterogeneity, which reports only annual crops.

Landscape 2, 4, 5, 7 and 12 have a significantly higher spatial crop heterogeneity than others. These landscapes are all crop dominated but are not per se mixed landscapes, suggesting that non-mixed landscape can still achieve high spatial crop heterogeneity by creating a mosaic with fewer crop types. All these landscapes are located north of the Alps.

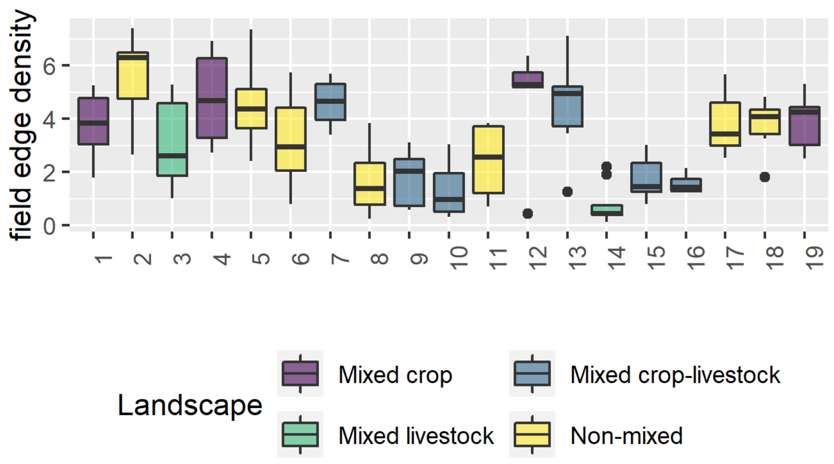


Figure 52 : biodiverisity : field edge density (SPLIT) per per landscape class

Figure 52 shows the densitiy of field edges which is highest for landscape class 2, a non mixed crop dominated lanscape with dominant cereals, pulses, industrial, and root crops, scattered accross Europe and 12, a mixed crop landsccape of dominant cereals, and grasses with an intensive dominant swine, and horses, mainly found in Denmark.

Lowest field margin density is found in landscape 14, mainly because it is a landsape dominaned by permanent crops not captured by the cropmap with annual crops based indictor.

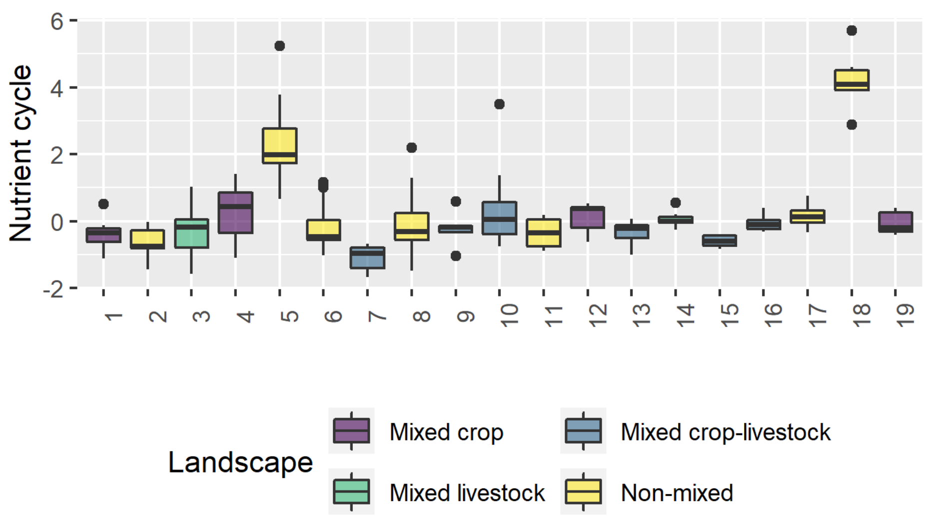


Figure 53 : supporting service nutrient cycle (first PCA loading on nitrogen and phosphorus balance) per landscape class

Concerning the nitrogen balance, those landscapes that are signicantly less balanced, hence prone to leaching, are landsape class 5, and landscape class 18, both of which are found in the Netherlands and Belgium with intensive livestock production (Figure 53).

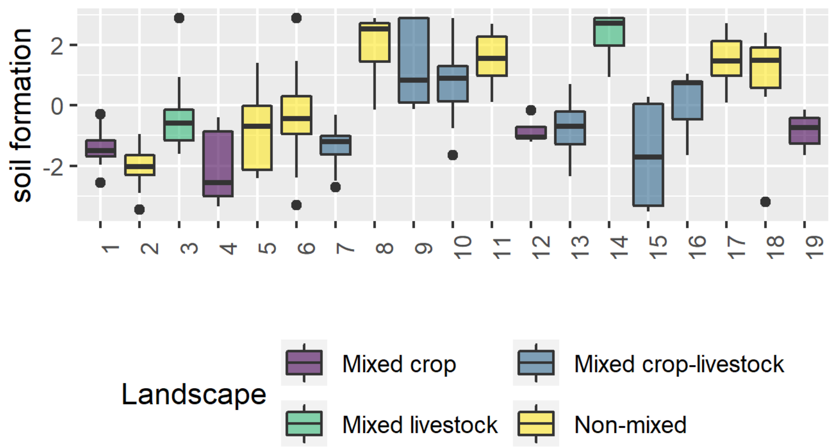


Figure 54 : supporting service soil formation (first loading PCA on soil management practices) per per landscape class

Landsape class 8, 11, 14 and 17 are highest and significantly different from other classes. With the exception of landcape 14, these are non mixed landscapes found in the united Kingdom, Ireland and in the Baltic states.

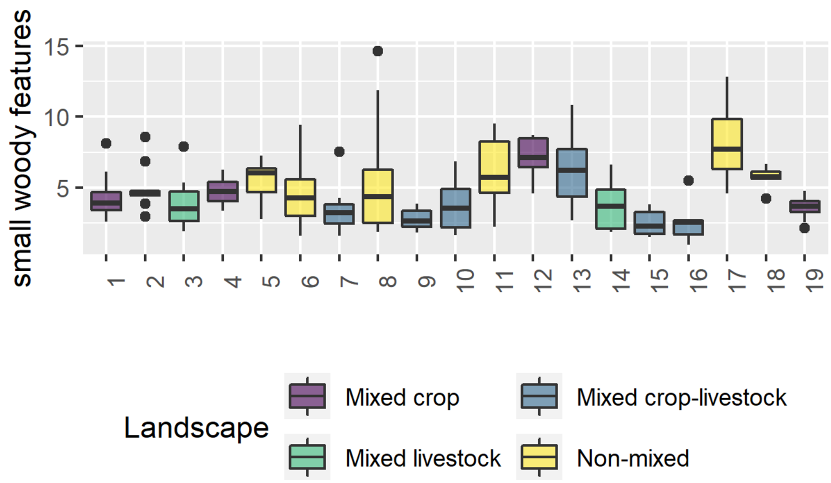


Figure 55 : supporting service small woody feature per per landscape class

High density of small woody feature are found in landscape class 11,12, 13, 17, 18 across very diverse catergory of landscapes, while the lowest are found in landscape 7, 9, 15, 16. This suggests that lowest small woody feature density is found in mixed crop-livestock production.

4.3.3 Assessing patterns of ESB within mixed landscapes

The previous section explored whether significant differences can be found for ESB provision across different landscape classes. Yet, it does not allow to look how ESB indicators correlated among each other. Because the different landscape classes are quite heterogenous, it is best to assess the patterns of ESB at landscape level (without aggregation to classes). This section explores the heterogeneity of ESB within the different landscape classes that were classified as mixed landscape categories (crop-livestock, livestock and crop), to understand if there are patterns of ESB that can be identified within mixed landscapes.

ESB rank (5 indicating highest and 1 lowest) for landscape class 1, shown in Figure 56 shows that these are landscapes with a higher crop heterogeneity and a lower soil formation, and a medium to good level of circularity.

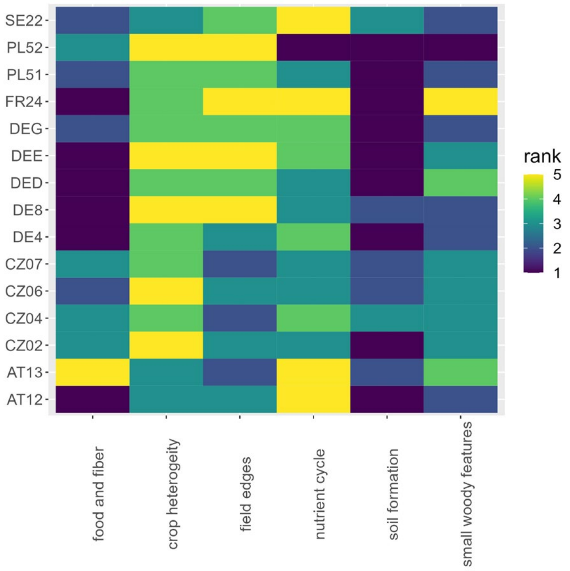


Figure 56 : Landcape class 1 (mixed crop) ranked ESB provision

Landscape class 3, shown in Figure 57, tend to have a lower provision of food and fiber and a lower spatial crop heterogeneity while showing no patterns relative to the other indicators

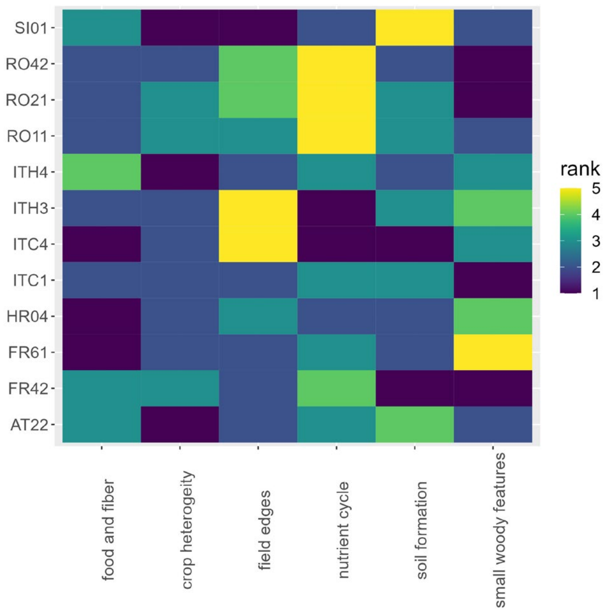


Figure 57 : Landscape class 3 (mixed livestock) ranked ESB provision

Landscapes in Class 4, shown in Figure 58 show generally a higher ESB provision except for soil formation. Also circularity related to the nutrient cycle is low.

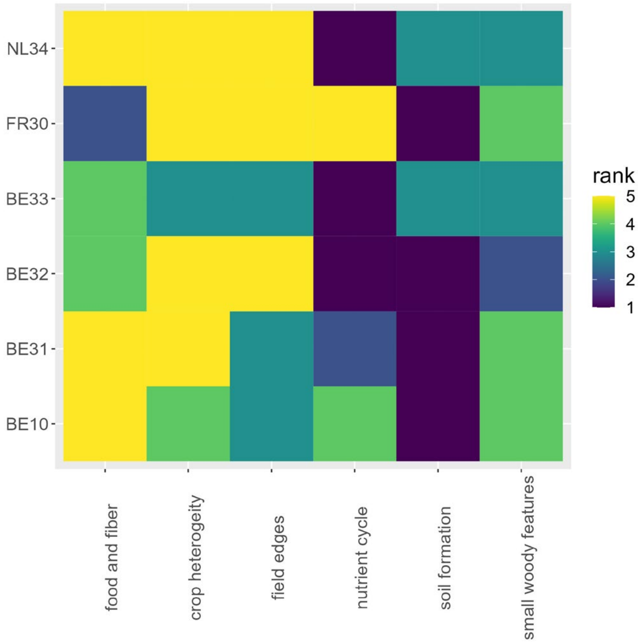


Figure 58 : Landscape class 4 (mixed crops) ranked ESB provision

Landscape class 7, in Figure 59, shows have a relatively good spatial crop heterogeneity, a medium to high density of field edges and a high level of circularity, suggesting that these landscapes provide another good combination of ESB provision, while providing a medium food and fiber provision.

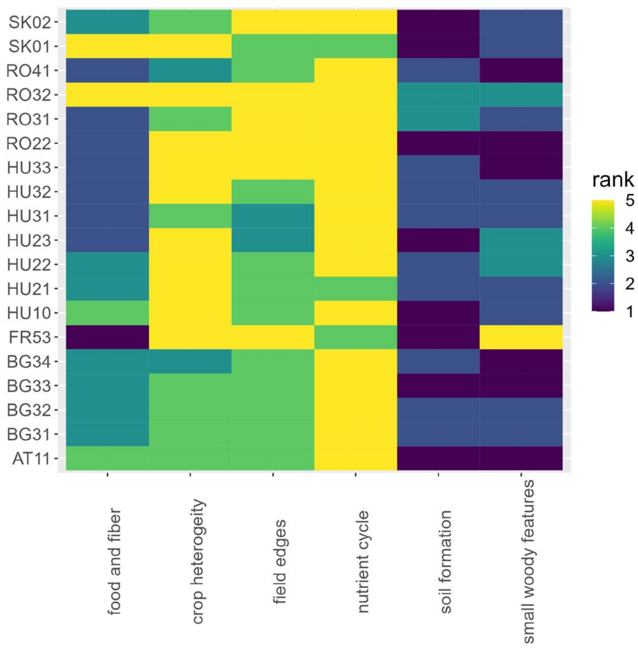


Figure 59 : Landscape class 7 (mixed crop livestock) ranked ESB provision

Landscapes in class 9 shown in Figure 60 tend to provide a medium of ESB with a tendency for a higher soil formation and lower density of small woody features.

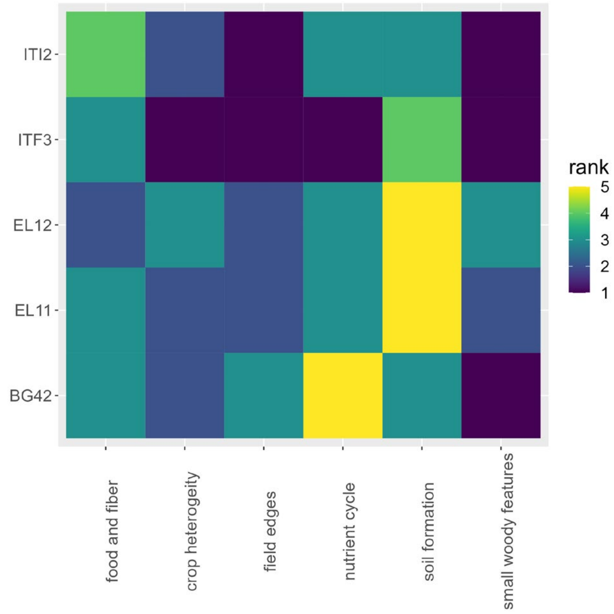


Figure 60 : Landscape class 9 (mixed crop livestock) ranked ESB provision

Landscapes in class 10, Figure 61, tend to score lower for spatial crop heterogeneity and field edges but a medium to high scoer for soil formation. There are the lanscapes in the mediteranian with an important part of permanent crops.

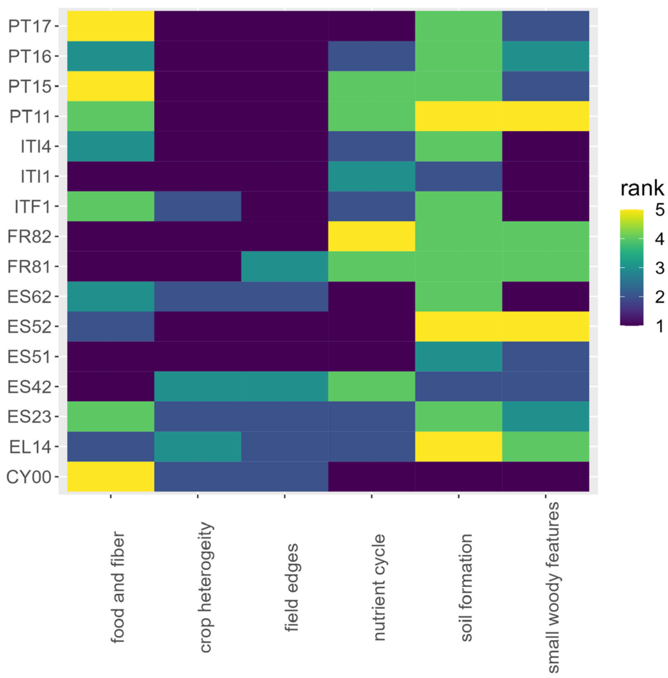


Figure 61 : Landscape class 10 (mixed crop livestock) ranked ESB provision

Landcapes in class 12, Figure 62, show a high biodiversity provision and a lower soil formation provison, while having a lower to medium circularity. Patterns related to food and fiber provision are unclear.

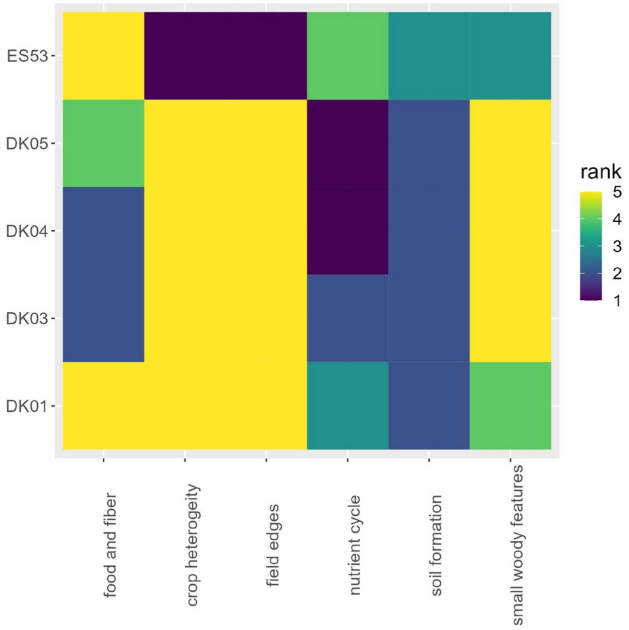


Figure 62 : Landscape class 12 (mixed crop) ranked ESB provision

Landscapes in class 13 (Figure 63) tend to perform well in terms of biodiviersity indicators as well as food and fiber provision. Howeverer, the Lithuanian landscape (LT00) as well as the Spanish landcape (ES 41) and Estonian landscape (EE00) are outliers in this group.

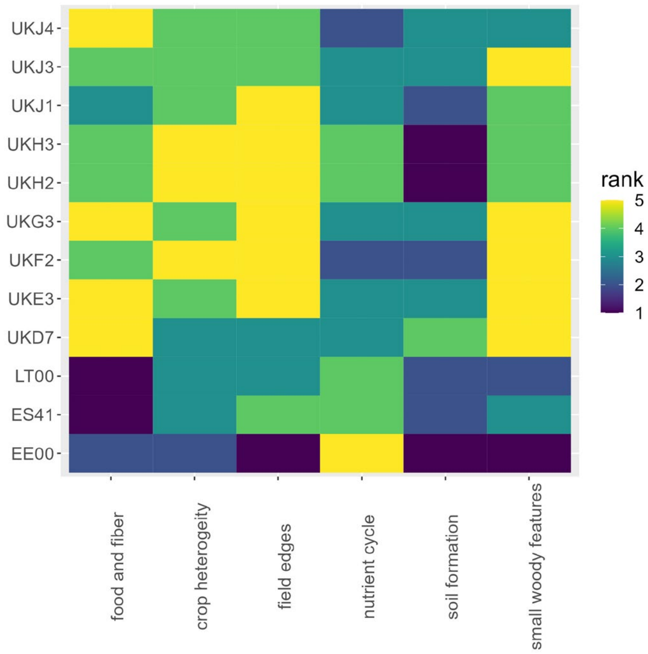


Figure 63 : Landscape class 13 (mixed crop livestock) ranked ESB provision

Landscapes in class 14 (Figure 64) are shaped by permanent crops, and therefore have a low spatial annual crop heterogeneity, but a high soil formation and low small wood features as the permanent crops (often wine, citrus or olives= do not count as small woody features. The provision of food and fiber tends to be high.

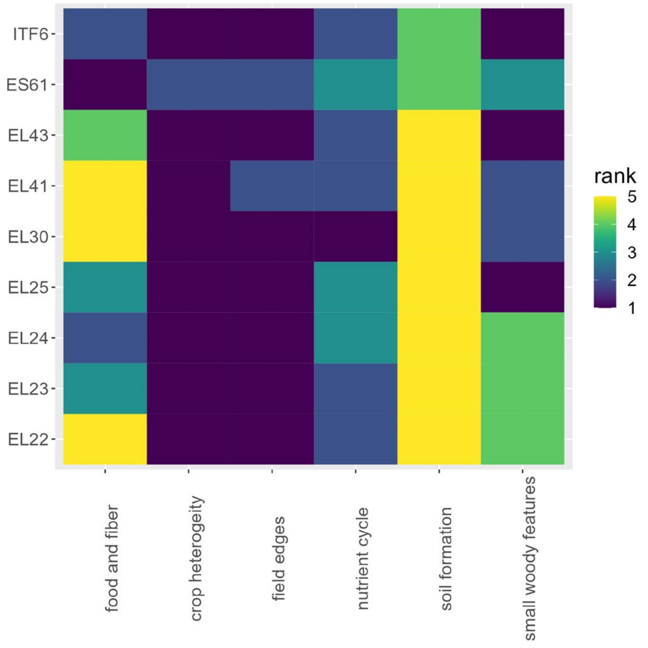


Figure 64 : Landscape class 14 (mixed livestock) ranked ESB provision

Landscapes in class 15 (Figure 65) tend to provide low ESB but perform quite well in terms of circularity related to nutrient cycles.

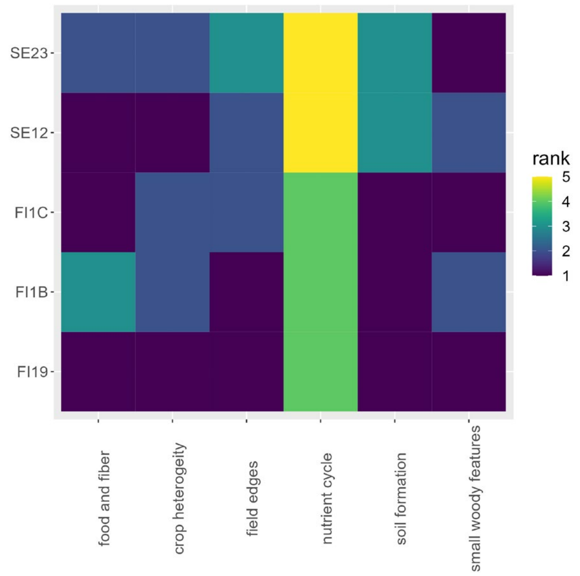


Figure 65 : Landscape class 15 (mixed crop livestock) ranked ESB provision

Mixed crop livestock landscapes in class 16 (Figure 66) are quite heterogenous. They seem to rank poor on small woody features, and generally have low ESB provision.

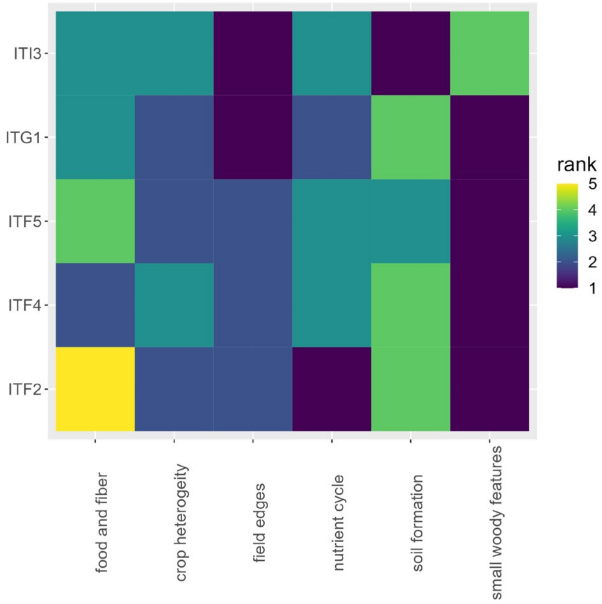


Figure 66 : Landscape class 16 (mixed crop livestock) ranked ESB provision

Landsapes in class 19 (Figure 67) tend to have a high spatial crop diversity with low small woody features with a low food and fiber provision and low soil formation.

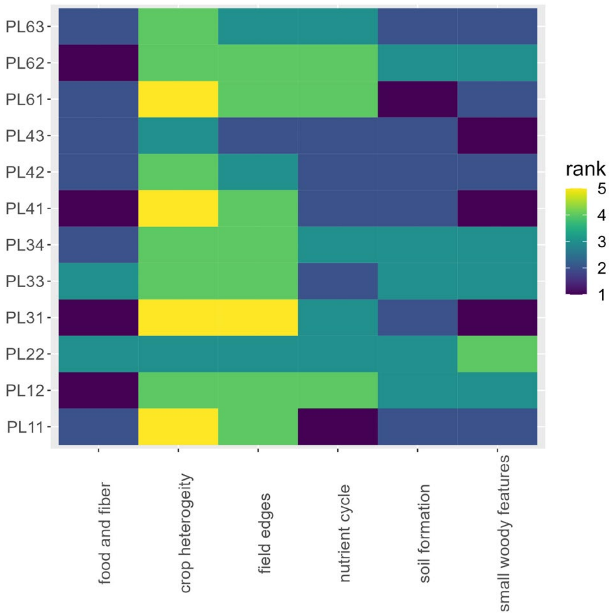


Figure 67 : Landscape class 19 (mixed crop) ranked ESB provision

Step 4: Identifying priority areas

4.3.4 Similarity analysis for mixed crop livestock landscapes

To do this, a similarity map was created for each mixed landscape category, suggesting where similar contexts could be found in Europe. We focus on mixed crop-livestock landscapes. The suitability maps show in green the level of suitability for mixed agricultural landscapes, where the dark green is more suitable than light green and grey suggests no suitability. The landscapes in yellow show where the landscape class for which the suitability is assessed is found. Landscapes in red are those that have been characterized as non-mixed, in purple those that are only mixed livestock in blue those that are only mixed crop. Hence landscapes with red or orange contour with any level of greens are priority area for that particular combination of crop and livestock activities represented by the landscape class.

Class 7, representing a mixed crop livestock landscape of dominant cereals, and industrial crops with dominant poultry, found in eastern Europe can be extrapolated to the whole of eastern Europe as well as to parts of France and northern Spain (Figure 68). This combination of mixed activities are not very suitable along the sea side in the northern Mediterranean, expect for the Apennine Mountains in Italy.

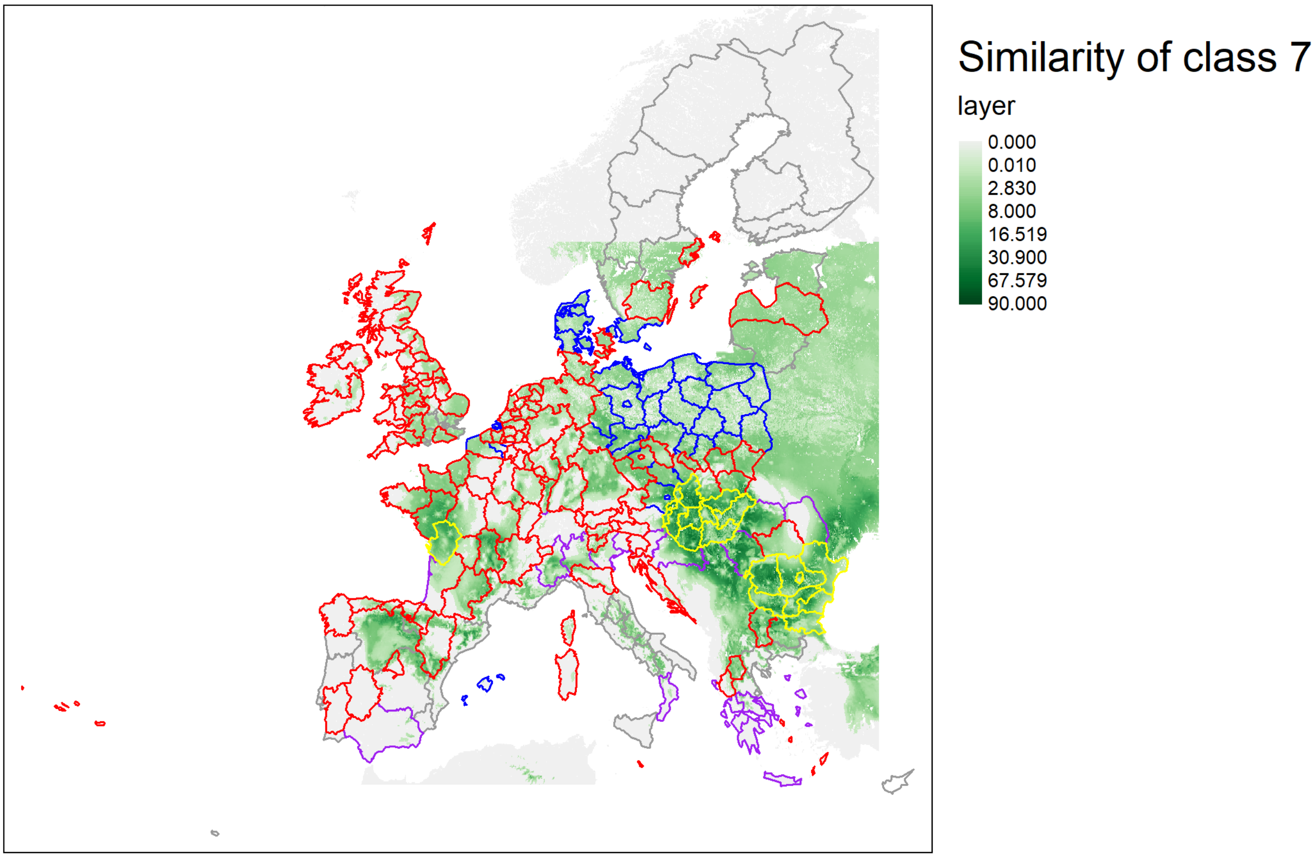


Figure 68 : similarity maps for landscape class 7 *Mixed* crop livestock landscape of dominant cereals, and industrial crops with a dominant poultry livestock system . Landscape boundaries are in yellow for the reference crop-livestock, in red for non-mixed, in purple for mixed livestock, in blue for mixed crop.

Landscape class 9 *Mixed* landscape of dominant industrial, and permanent crops with dominant sheep found mainly in Italy and Bulgaria can be extrapolated to northern Spain and the French atlantic and Mediterranean coast (Figure 69).

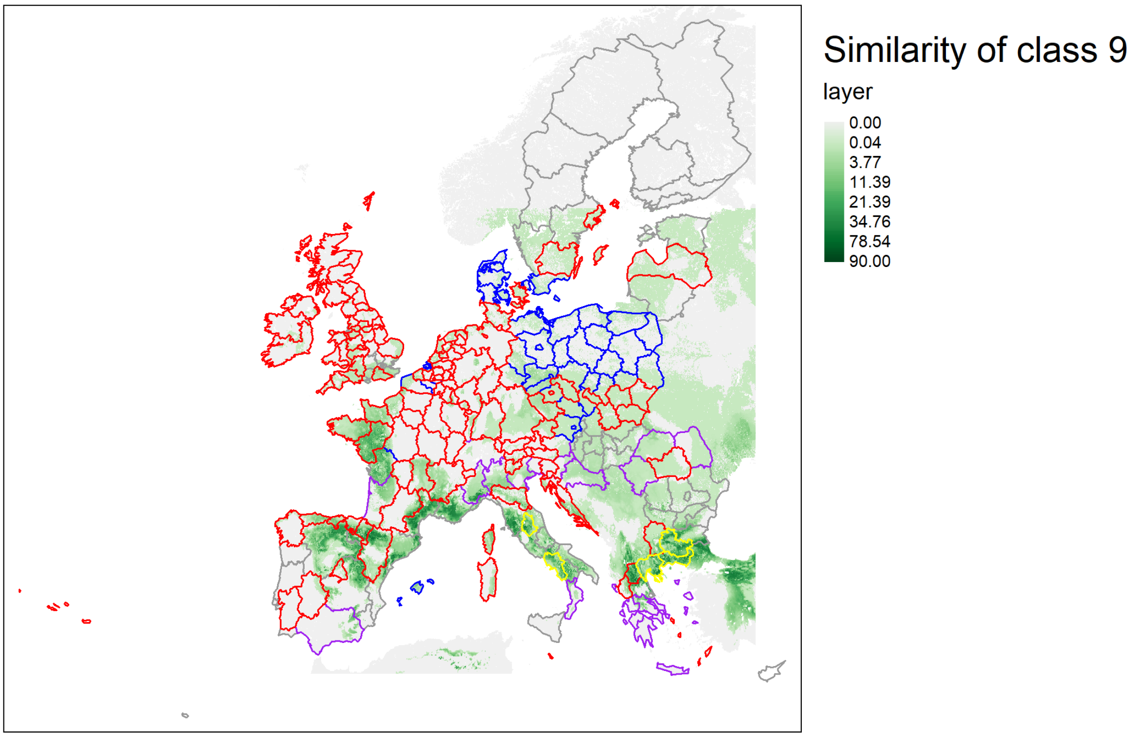


Figure 69 : similarity maps for landscape class 9 : *Mixed* landscape of dominant industrial, and permanent crops with dominant sheep Landscape boundaries are in yellow for the reference crop-livestock, in red for non-mixed, in purple for mixed livestock, in blue for mixed crop.

Similarity map for landscape class 10, the mixed crop livestock landcape of dominant permanent crops with dominant sheep, and goat in Figure 70 shows that this is a particularly interesting combination of mixed activities that is suitable for southern Europe, and is the only class of mixed landscape that can be extrapolated to southern Spain, yet not suitable at all for central Europe.

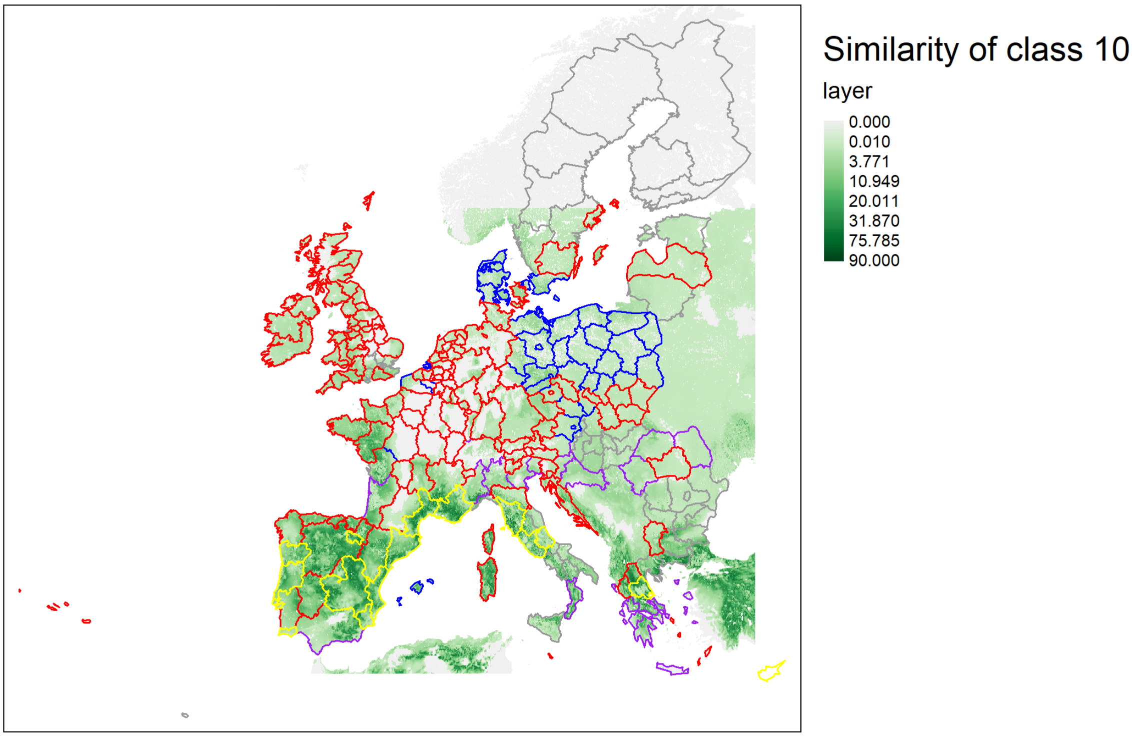


Figure 70 : similarity maps for landscape class 10 : Mixed crop livestock landcape of dominant permanent crops with a dominant sheep, and goat Landscape boundaries are in yellow for the reference crop-livestock, in red for non-mixed, in purple for mixed livestock, in blue for mixed crop.

Lanscape class 13, the mixed crop livestock landscape class of dominant industrial crops, and with an intensive dominant sheep and horses found in the Baltic states, non costal area of England and central Spain can be extrapolated almost everywhere in Europe with the exception of southern Spain, Italy or Greece. It is particularly suitable to Eastern Europe.

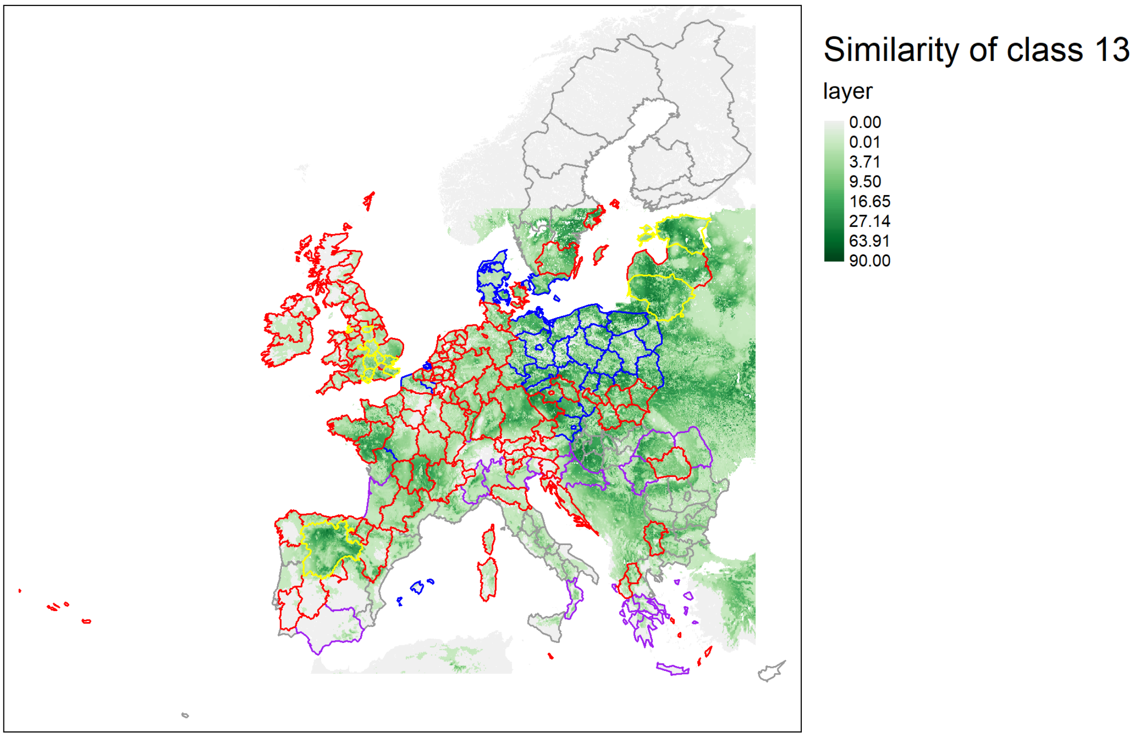


Figure 71 : similarity maps for landscape class 13 : *Mixed* crop livestock landscape of dominant industrial crops, and with an intensive dominant sheep and horses. Landscape boundaries are in yellow for the reference crop-livestock, in red for non-mixed, in purple for mixed livestock, in blue for mixed crop.

Mixed crop livestock landscape of dominant cereals, pulses, and grasses with a dominant extensive swine in Class 15 are mainly found in Scandinavia (Figure 72). It is a very particular northern system that is unlikely to be exrapolated elsewhere than the nordic countries. It could therefore be an option for the non mixed landscapes in Latvia and Sweden but nowhere else.

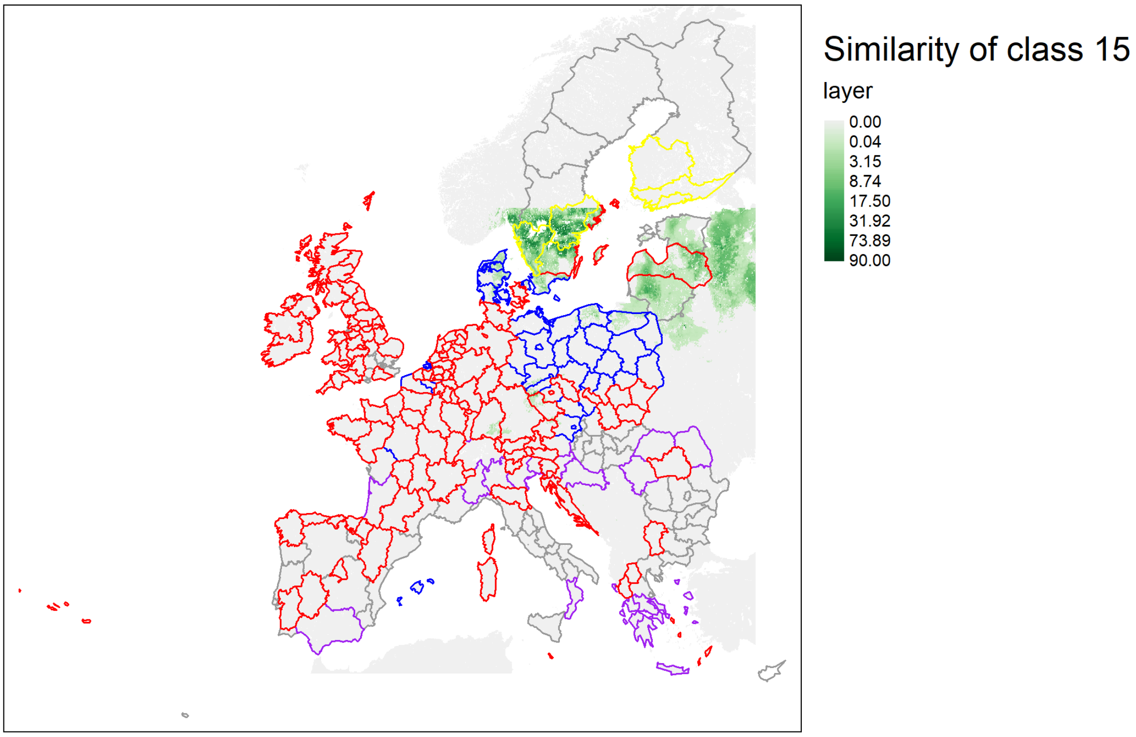


Figure 72 : similarity maps for landscape class 15 *Mixed* crop livestock landscape of dominant cereals, pulses, and grasses with a dominant extensive swine. Landscape boundaries are in yellow for the reference crop-livestock, in red for non-mixed, in purple for mixed livestock, in blue for mixed crop.

Finally, mixed crop-livestock systems of vegetables, grasses, and permanent crops reprsented in class 16 and mainly found in Italy can be extrapolated mainly to other regions of Italy and around the mediteranian coast.

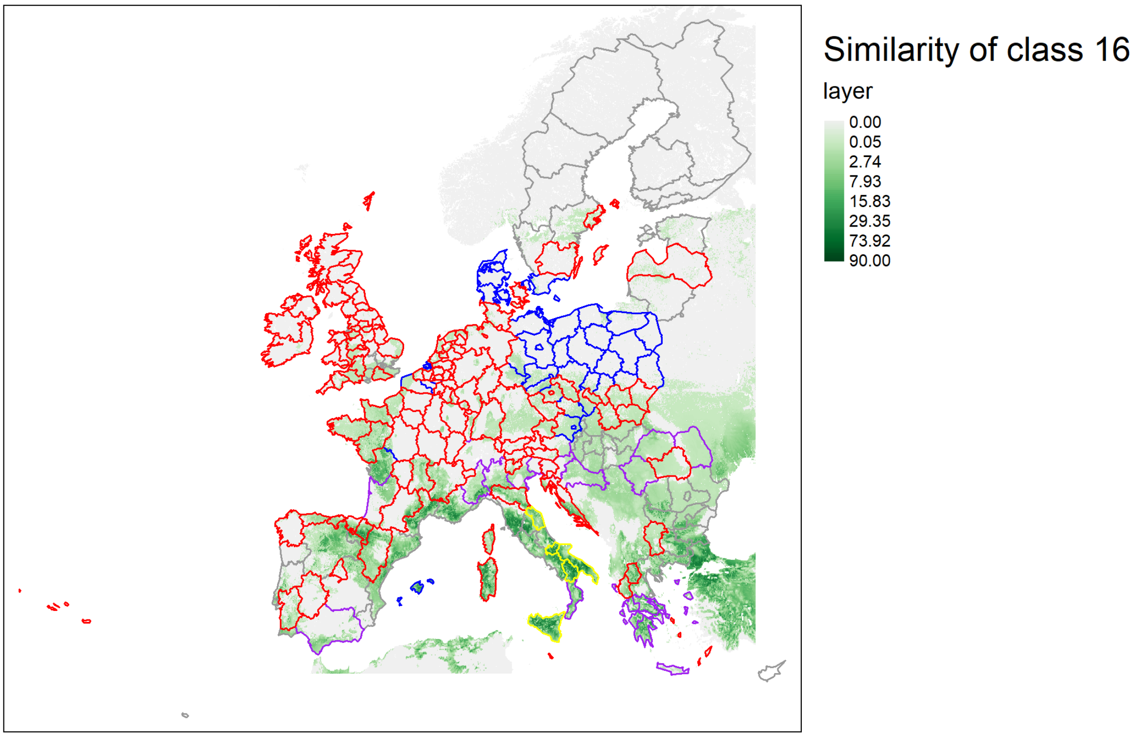


Figure 73 : similarity maps for landscape class 16 : Mixed crop-livestock system of vegetables, grasses, and permanent crops. Landscape boundaries are in yellow for the reference crop-livestock, in red for non-mixed, in purple for mixed livestock, in blue for mixed crop

4.4 Non-mixed crop livestock landscapes with the highest potential

While the maps above (Figure 68-73) show where each particular mixed crop livestock could be suitable, Figure 74 presents the sum of all the precedent maps. It shows which areas have a better option than others to become more mixed.

While landscapes in Romania, Eastern Germany and Czech Republic have a high overall suitability for mixed crop-livestock landscapes, other areas such as southern Spain, central France and the Alpine Arc have much less option for mixed landscape, following the criteria that we set. This does not mean that these locations cannot become more mixed, but that currently no mixed crop-livestock system was observed in such a context.

This includes central France, West Germany and Switzerland, these areas that have been classified as non-mixed bovine dominant system with high share of permanent grassland. In areas with high permanent grassland, there are only limited options for diversification into crop, moreover EU forbids the conversion of permanent grassland into cropland.

Southern Spain and Portugal in Class 8 as well as Southern Spain and Greece in Class 14 are having important shares of permanent grassland combined with bovine and in the Mediterranean it is combined with permanent crops such as olives.

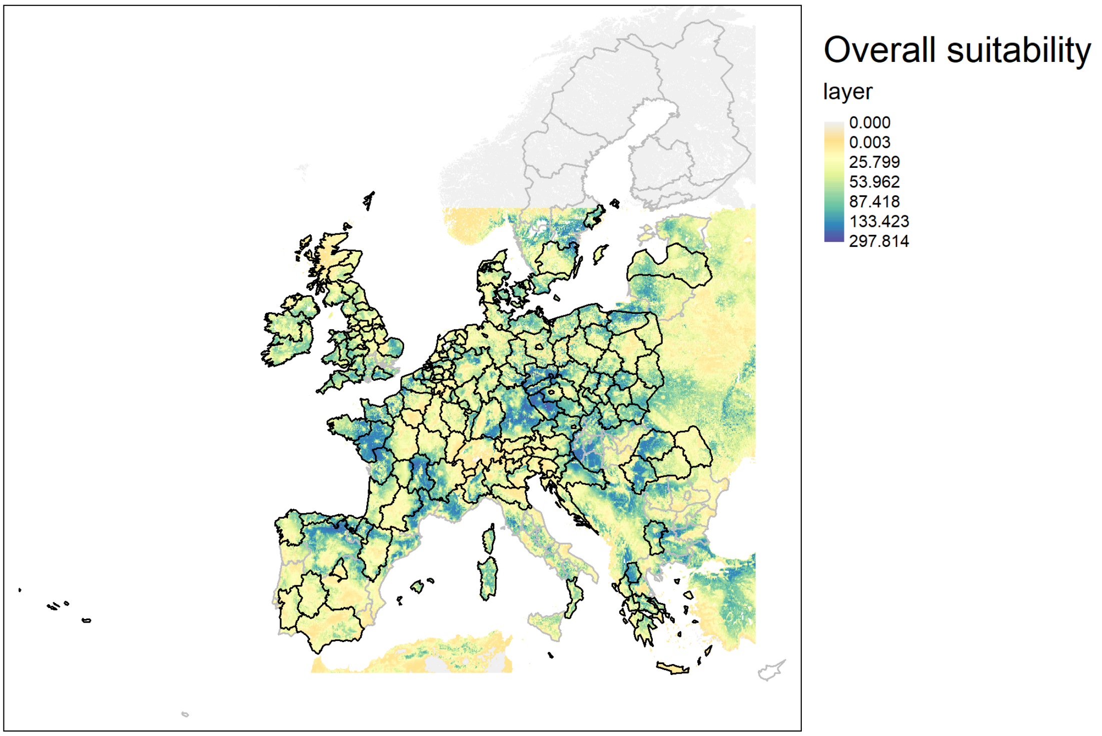


Figure 74 : overall suitability for mixed crop livestock with non mixed, mixed crop or mixed livestock landscapes in black.

Also the Netherland, in class 18, has relatively low potential for mixed systems, and also has a very high share of permanent grasslands.

4.5 Step 5 : exploring cross-scale interactions

Alluvial flows were computed for those landscape classes that were considered as mixed crop-livestock to assess if these landscapes emerge from a network of mixed farms or from a network of diverse specialized farms.

Figure 75 shows that the Romanian mixed landscapes emerge from about 1/3 of mixed farms while 2/3 are combinations of specialist grazing livestock or specialized granivore farms combined with specialized field crop farms.

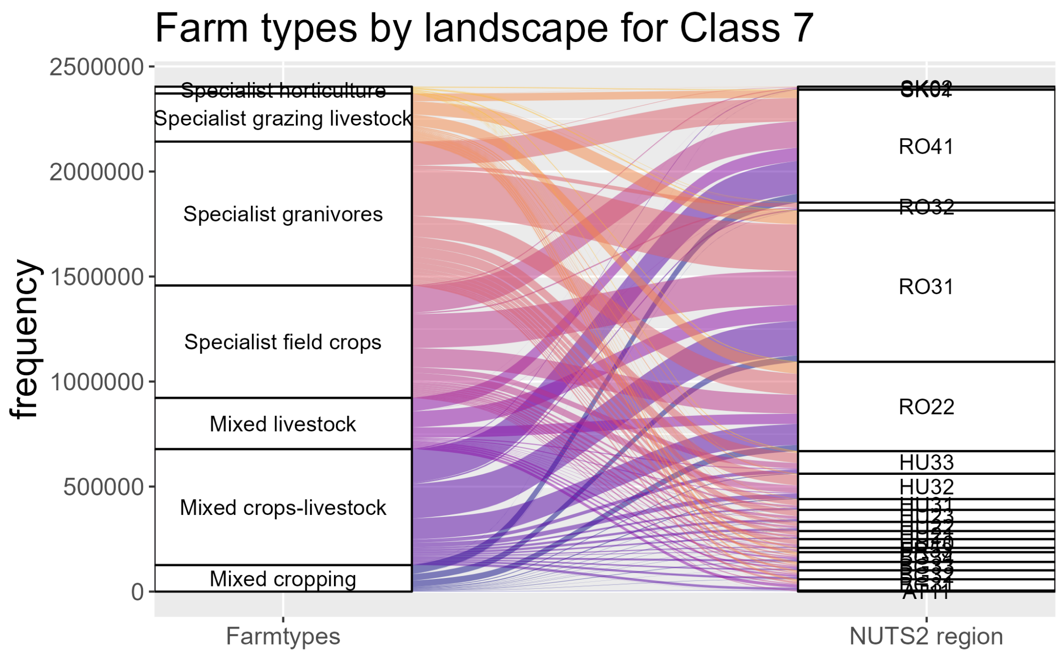


Figure 75 : Mixed crop-livestock landscape of dominant cereals, and industrial crops in the cropping system with a dominant poultry

Figure 76 shows that the Bulgarian landscapes found in Class 9 are like those in Class 7 shaped by mixed farms as well as a combination of specialized crop and specialzied livestock farms. Interesting is the fact the other landscapes emerge mainly from specialized permanent crops and specialist crop farms with very few mixed farms. This suggests that though most of the income of the farms in these regions are from crops, leading to their classification into specialist crop or permanent crop farm, NUTS2 level suggests that these farms have an important number of livestock. This suggest that livestock in the region might not be economically important, explaining why these farms classify as specialist crop farms in economical terms.

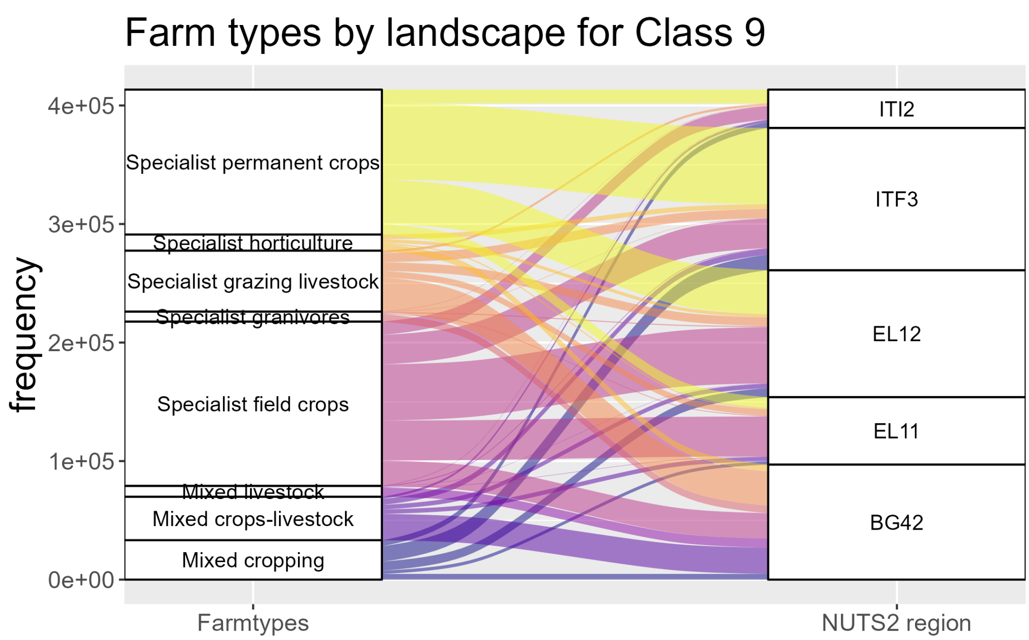


Figure 76 : Class 9 : Mixed crop-livestock landscape of dominant industrial, and permanent crops in the cropping system with a dominant sheep

Figure 77 shows that mixed farms are shaping mainly the Portuguese landscapes, combined with some specialized crop and specialized livestock farms. Interesting are also the Spanish landscapes that are shaped by only permanent crop specialist based on economic criteria but own livestock because they classified as a mixed crop-livestock landscapes.

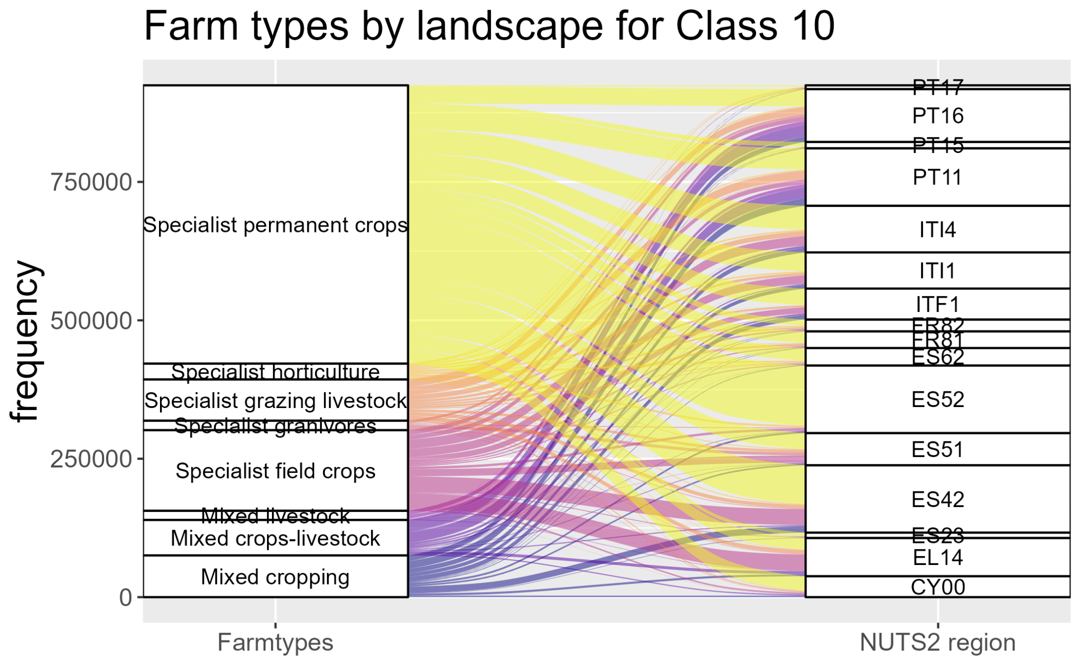


Figure 77 : Class 10: *Mixed* crop-livestock landscape of dominant permanent crops in the cropping system with a dominant sheep, and goat

Figure 78 shows that all mixed crop-livestock landscapes emerge from the combination of specialist farms including horticulture, field crops, grazing livestock and granivores. Mixed farms play a very marginal role in the emergence of these mixed landscapes.

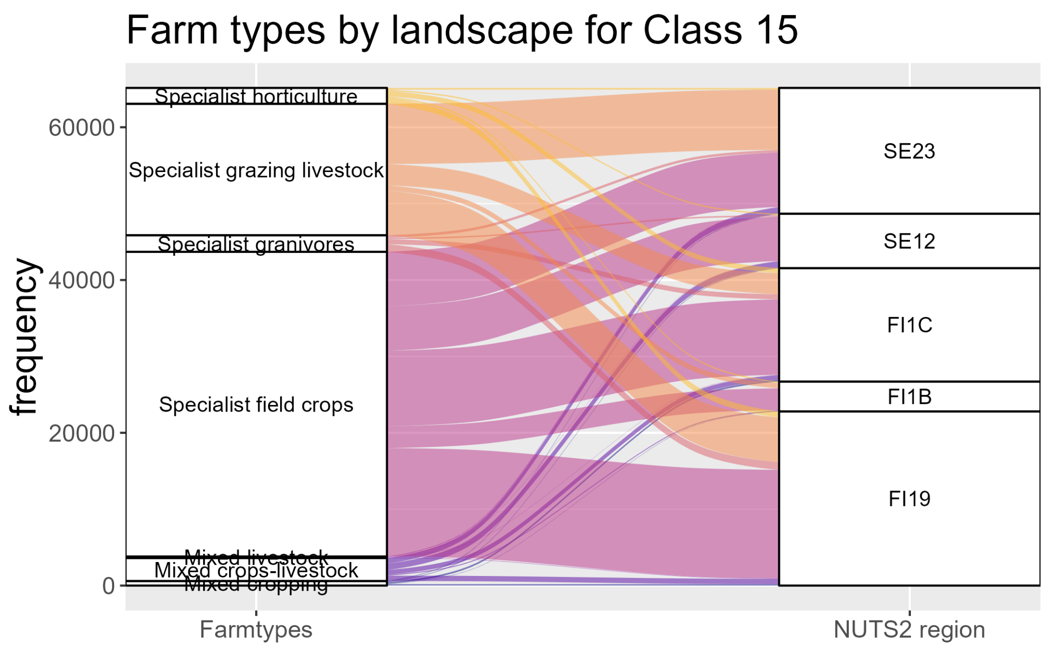


Figure 78 : Class 15 Mixed crop-livestock landscape dominant cereals, pulses, and grasses in the cropping system with a dominant extensive swine livestock system

Figure 79 shows similarly to Class 9 and 10 that mixed landcape emerge from permanent crop specialists.

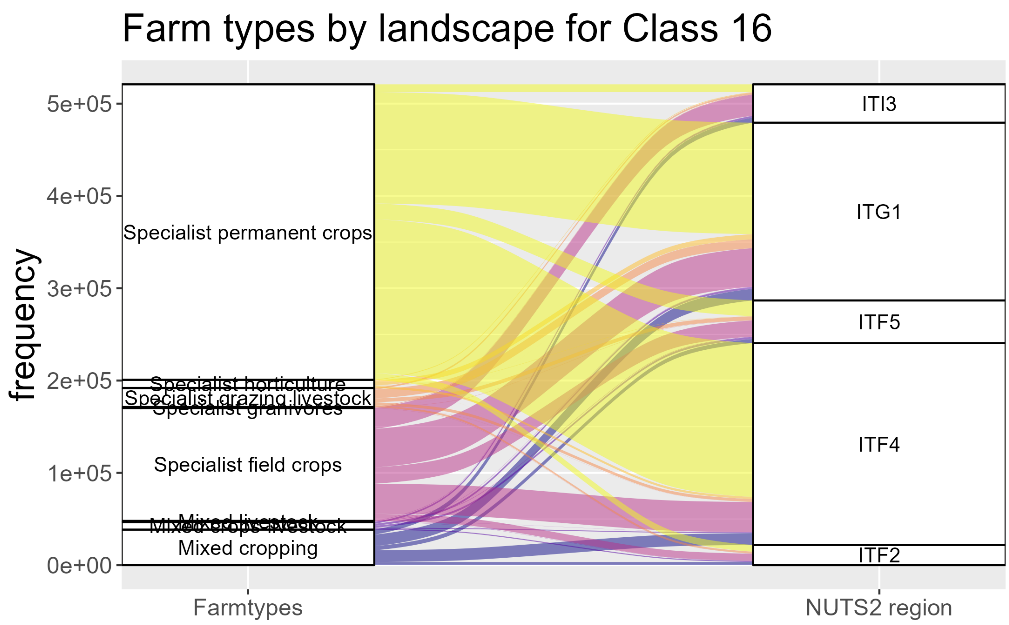


Figure 79 : Class 16 mixed crop-livestock landscape of dominant vegetables, grasses, and permanent crops in the cropping system

5 Discussion and future work

5.1 A reflection on the methods

In this deliverable, we present the entirety of our exploratory work, showcasing a multi-step approach that, while comprehensive, is notably complex. A significant limitation of this approach stems from its claim of operating at a landscape scale, defined in our study as corresponding to the second level administrative boundaries (NUTS2). However, there is an incongruence in the methodology: the classification into 'mixed landscapes' in step 2 is derived from step 1, which delineates much larger areas than those defined by our landscape scale. This method is predicated on the hypothesis that landscapes within a given class exhibit similar combinations of crops. Yet, such a broad-brush approach leads to a over the intrinsic heterogeneity within these areas.This could potentially lead to a homogenization of data, where nuanced variations and distinct characteristics of smaller landscapes are lost or underrepresented. The assumption that larger landscape classes can accurately reflect the conditions of smaller, individual landscapes within them may not hold true in all cases, especially in regions where agricultural practices and crop distributions vary significantly over short distances.

The resulting maps produced in this study are preliminary and have not yet undergone validation. We have planned an expert validation process to take place during the upcoming General Assembly (GA). This critical step will be instrumental in determining the robustness and accuracy of our methodology. The insights gained from this expert review will reveal whether our method is sound or if it requires significant revisions. Should the validation process uncover any issues, we are fully committed reviewing the approach presented in this deliverable. It is this upcoming validation process that will ultimately confirm the validity of our approach and the reliability of the maps generated, ensuring that they accurately represent the landscapes they are intended to depict.

5.2 A reflection on the spatial distribution of mixed landscapes

About 20 % of the European landscapes were classified as mixed crop-livestock and they are found mainly in the Mediterranean zone as well in as in Scandinavia (Figure 80), both areas facing climatic challenges.

Many mountainous areas, namely the Alps, the Iberian Mountains, the Carpathian or the Balkan Mountains, are areas that are difficult to crop and that are mainly grassland dominated. As a result, these areas are used for grazing livestock, which classify as non-mixed landscape or as mixed livestock landscape. Also, the United Kingdom and Ireland fall under this category of grassland dominated landscapes.

Mixed crop landscapes dominate in Poland, East Germany, Denmark, Belgium as well as a couple of landscapes scattered across the north of the Alps, suggesting that wetter zones where crops can grow easier tend to have a higher crop diversity, compared to Southern Europe that is mainly shaped by permanent crops.

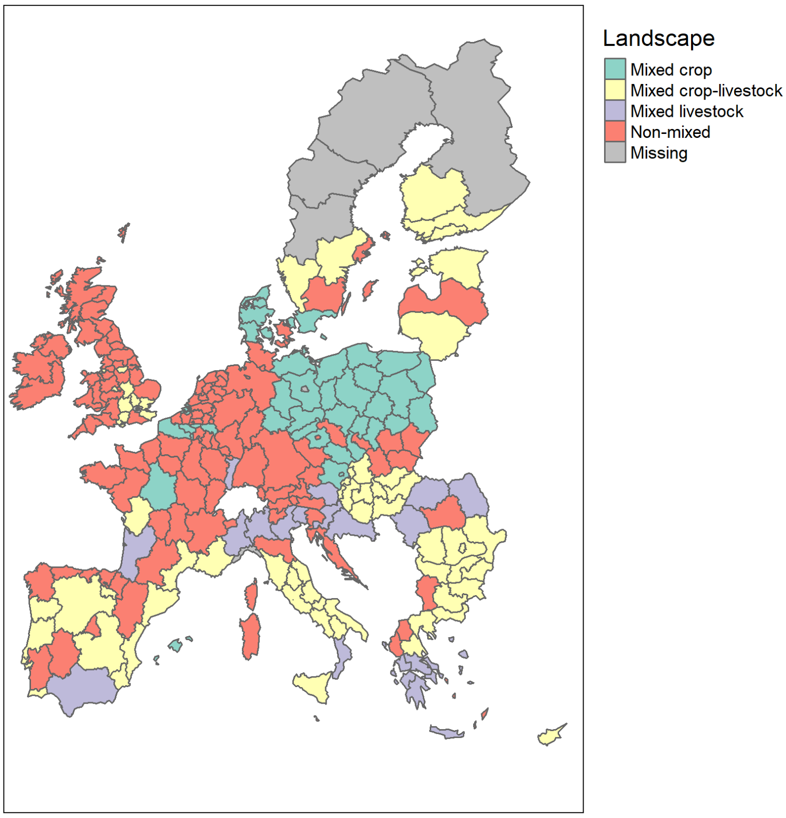


Figure 80 : landscape classification into mixed crop, mixed livestock, mixed crop-livestock and non mixed in Europe.

Specialisation both of farm and regions over the last decenia allowed to exploit returns to scale and enhance efficiency and profitability (Schut et al., 2021). Benefits of such a specialisation are the highest when farms and regions specialize in what growth best (Campi et al., 2020) or are located near to ports along the major trade routes (in the Netherlands and Danemark) that give cheap access to imported animal feed (Schut et al., 2021). Unsurprisingly, those landscape that remained more mixed are found in more marginal areas with less good access to world markets and less good growing conditions (water, soil quality) , where the potential gain from specialisation is likely to be lower.

5.3 ESB provision of mixed landscapes

5.3.1 Potential trade-offs and synergies between ESB

No patterns could be found linking agricultural ESB provision to mixed landscapes. In general, the heterogeneity of ESB provision with mixed landscapes was bigger than among non-mixed landscapes. Trade-offs can be observed between spatial crop heterogeneity and soil formation. While spatial crop heterogeneity is likely to be high in areas with a focus on crops, low tillage and whole year-round cover crops is much more common in areas dominated with permanent grassland.

Circularity, meaning being among the landscapes that have closed the nutrient cycle better (being without surplus or only with slight surplus) are found in Eastern Europe, more particularly Southern Romania and Bulgaria, is a system that tends to be shaped by smaller - often family-farms, that often are more diverse. Not surprisingly the food and fiber provision tend to be lower. *Except very few exceptions, most crop-livestock landscapes perform well to medium on the circularity measure, low performance is mainly found in non-mixed landscapes associated with intensive livestock keeping.*

While food and fiber provision could be expected to vary quite drastically across Europe, the performance is homogenous, suggesting that each landscape produces what gives the best local returns.

5.3.2 Do we have the right ESB metrics?

It is interesting to notice that areas with permanent crops and permanent grassland tend to have a lower performance on the biodiversity indicators, the spatial crop heterogeneity, the density of field edges and the small woody features. This can be explained by the metrics used. Both the spatial crop heterogeneity and the field edge density are delivered from the high-resolution crop map, that separated between different annual crops, grass and permanent crops. As grass and permanent crops are undifferentiated between different permanent crops or different intensities of grassland productions, the landscape metrics approach we have used does not allows to differentiate different patches, suggesting a low diversity in big fields. Also using small woody features as an indicator for biodiversity, is driven by a perennial crop production thinking. In areas, alternating annual crops with permanent crops can offer diverse habitat, not requiring any small woody features. As a result, most livestock-dominated and permanent crop landscapes have a lower ecosystem provision than those dominated by crops. This suggests that more effort should be done to enhance biodiversity metrics to account for diversity in permanent crops and in grassland, to have a fair comparison between the different landscapes.

Our approach focuses on agricultural ESB provision, it overlooks the fact that some of these mixed landscapes tend to be found in more marginal areas. In these areas, it is likely that agriculture takes place in diverse landscapes not just focusing on annual crops, alternating agriculture with semi-natural and natural areas. Hence, not all ESB provision comes from agricultural land, but also from the more natural lands, which is not accounted for in our approach.

For example, agricultural landscapes with high amounts of natural forests as found in Scandinavia, provide sufficient habitat and connectivity through proximity to forest and therefore small woody features are an unnecessary feature for biodiversity. Future work should focus on finding more appropriate agricultural ESB indicators that are able to account for the service that results from the proximity of semi natural and natural areas to agricultural land.

5.4 Which farm scale dynamics lead to mixed landscapes?

Three dynamics have been identified to understand the emergence of mixed landscapes. Firstly, mixed agricultural landscapes can emerge from landscapes that combine about the same number of mixed farms, specialized crop farmers and specialized livestock farmers. Secondly, mixed agricultural landscapes can emerge from combination of specialized farmers solely. Thirdly, they emerge in landscapes shaped by specialists in permanent crops. This suggests that farmers that are classified as specialists in permanent crops based on their income, might combine this activity with livestock, such as grazing sheep or goats under olive trees, yet the income on livestock is marginal, explaining why these farms are not considered as mixed. This shows the limitation of using Eurostat data instead of FADN when doing the cross-scale analysis. FADN data would allow to make a much more detailed farm typology, understanding how farmers combine crops, livestock and trees rather than based on the economic value of their activities as done in Eurostat. This would allow to gain insight on how farmers networks contribute to the emergence of mixed landscapes. Further work linked to WP 6 will focus on how to better understand the cross-scale interactions and how farm level decision could be influenced through the diversity of the farm network.

5.5 Can Europe be more mixed?

The suitability mapping shows that there are locations that have a similar context to already existing mixed landscapes, hence more mixed landscapes could emerge. Yet, options to become more mixed are not evenly spread. Locations dominated by permanent grassland have less options to diversity than areas with crops.

Also, supporting the emergence of more mixed landscapes will not *per se* increase the agricultural ESB provision. There are already non-mixed landscapes today with a relatively high provision of ESB, while there are mixed landscapes with relatively low ESB provision. The only pattern found is that mixed landscapes tend to perform better in terms of circularity than livestock dominated non-mixed landscape. *Promoting more mixed landscapes under these premises could enhance circularity, as well as enhance resilience of the landscapes, as diversity can help the area to cope with shocks such as extreme climate events but our results do not allow to say anything about provision of agricultural ecosystem services*.

Promoting more mixed landscapes does not *per se* require more mixed farms, it can be achieved through the right combinations of specialist farms. More research is needed on what it takes to make this mixed farmers networks emerge, a topic that is covered by task 3.2.

The suitability analyis thas shown that quite some region have few options to become more mixed. This does not mean that these areas are doomed, but that non of the current forms of mixed farming system was found in a similar context. This suggest, that promoting the emergence of more mixed landscape in those areas requires the development of new forms of mixed farming systems that are not yet broadly observed, and already presented in our pan European dataset. Supporting the emergence of such novel forms of mixed farming system requires experimenting, learning and sharing innovations related to more mixed farming. This is the main focus workpackage 1 of the MIXED project.

5.6 Supporting a transition towards more mixed landscapes

The priority area finding in this deliverable is rooted in the idea that the bio-physical and to a certain extent the socio-economic context define conditions from which a mixed agricultural landscape can emerge. However, existing mixed agricultural landscapes have not emerged just out of the blue thanks to biophysical conditions that were met. Mixed agricultural landscapes have evolved over years in specific market and policy environments. Landscape evolution is ultimately path-dependent, historical choices are influencing the option that a landscape has today. Therefore, promoting the emergence of more mixed agricultural landscapes requires understanding this historical patterns and leverage points that can support the transition towards more mixed landscapes. More research is needed to identify internal leverage points (eg. key actors in food value chains) and external drivers for system change (eg. policies or campaigns) to support the emergence of more mixed landscapes.

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Appendix

6.1 Supplementary tables

Appendix Table 1 : :Overview of Eurostat data: Crop-tree types by Eurostat classification (considered crop-tree types in LPA are highlighted in pink) (Eurostat - European Commission, 2022; Eurostat, 2020)

Category	Subcategory	Full name	Unit
C0000		Cereals for the production of grain (including seed)	ha
	C1110	Cereals (excluding rice) for the production of grain (including seed)	ha
	C1120	Durum wheat	ha
	C1200	Rye and winter cereal mixtures (maslin)	ha
	C1300	Barley	ha
	C1400	Oats and spring cereal mixtures (mixed grain other than maslin)	ha
	C1500	Grain maize and corn-cob-mix	ha
	C1600_ 1700_1900	Triticale; Sorghum; Other cereals for the production of grain n.e.c.	ha
	C2000	Rice	ha
I0000		Industrial crops	ha
	I1100	Oilseeds	ha
	I1110	Rape and turnip rape seeds	ha
	I1120	Sunflower seed	ha
	I1130	Soya	ha
	I1140	Linseed (oilflax)	ha
	I1150_ 2300	Cotton seed and fibre	ha
	I1190	Other oilseed crops n.e.c.	ha
	I2000	Fibre crops	ha
	I2100	Fibre flax	ha

	I2200	Hemp	ha
	I2900	Other fibre crops n.e.c.	ha

Category	Subcategory	Full name	Unit
	I3000	Tobacco	ha
	I4000	Hops	ha
	I5000	Aromatic, medicinal and culinary plants	ha
	I9000	Other industrial crops n.e.c.	ha
P0000		Dry pulses and protein crops for the production of grain (including seed and mixtures of cereals and pulses)	ha
PECR		Permanent crops	ha
	PECR9_ H9000	Other permanent crops including other permanent crops for human consumption	ha
	PECRS	Permanent crops under glass or high accessible cover	ha
	F0000	Fruits, berries and nuts (excluding citrus fruits, grapes and strawberries)	ha
	T0000	Citrus fruits	ha
	W1000	Grapes	ha
	O1000	Olives	ha
R0000		Root crops	ha
	R1000	Potatoes (including seed potatoes)	ha
	R2000	Sugar beet (excluding seed)	ha
	R9000	Other root crops n.e.c.	ha
V0000_S0 000		Fresh vegetables (including melons) and strawberries	ha
G0000		Plants harvested green from arable land	ha
J0000		Permanent grassland	ha

Figure 81 : Overview of GAEZ yield data (FAO and IIASA, 2021a; Fischer et al., 2021)

GAEZ abbreviation	Full name	Definition: FAOSTAT primary crops	Given unit	International price ($/ton) for aggregations
whe	Wheat	Wheat	t/ha	155
rcw	Wetland rice	Rice, paddy	t/ha	200
mze	Maize	Maize	t/ha	125
brl	Barley	Barley	t/ha	115
mlt	Millet	Millet	t/ha	170
srg	Sorghum	Sorghum	t/ha	130
oce	Other cereals	Buckwheat; Quinoa; Fonio; Triticale; Canary seed; mixed Grain; Cereals nes; Rye; Oats; Poppy seeds (pop corn)	t/ha	307.5
olv	Olives	Olives	t/ha	500
rsd	Rapeseed	Rapeseed	t/ha	330
sfl	Sunflower	Sunflower seed	t/ha	300
rt1	Potato and sweet potato	Potatoes; Sweet potatoes	t/ha	105
soy	Soybean	Soybean	t/ha	250
sub	Sugar beet	Sugar beet	t/ha	32
cot	Cotton	Seed cotton	t/ha	525
tob	Tobacco	Unmanufactured tobacco	t/ha	1500
pls	Pulses	Bambara beans; beans, dry; broad beans, dry; chick peas; cow peas, dry; lentils; peas, dry; pigeon peas; pulses, other	1000 GK$/ha	235-450
frt	Fruits and Nuts	Bananas; Plantains; Oranges; Tangerines and mandarins and clementines; Satsumas; Lemons and limes; Grapefruit and pomelo; Citrus fruit, nes; Apples; Pears; Quinces; Spome fruit, nes; Apricots; Sour cherries; Cherries; Peaches and nectarines; Plums; Stone fruit; Strawberries; Raspberries; Gooseberries; Currants; Blueberries; Cranberries; Berries, nes; Grapes; Figs; Persimmons; Kiwi fruit; Mangoes; Avocados; Pineapples; Dates; Cashewapple; Papayas; Tropical fruit (fresh), nes; fresh fruit, nes	1000 GK$/ha	Not specified

Some GAEZ v4 crop variables are difficult to calculate as exact information on calculation and sources for the respective international prices lack. For the crop summary “other cereals” no exact information about the international price is provided, thus, the average of the available price range is taken. With respect to the “potato and sweet potato” crops, the international potato price has been selected for further calculation since potatoes take a larger share in agricultural production in the EU than sweet potatoes (Eurostat, 2020b). The data is aggregated in 1000 GK$/ha, for those where a price range is given GAEZ data was already calculated in GK$/ha, the others were multiplicated by their respective price.

Appendix Table 2: **Overview of Eurostat data: Livestock animals by Eurostat classification** (Eurostat - European Commission, 2021a; Eurostat: Statistics Explained, 2018, 2019a, 2019b, 2019c, 2019d, 2019e, 2020)

Eurostat abbreviation	Full name	Definition	Livestock categories
A1000	Live horses, asses, mules and hinnies	This class covers all animals from the horse family (equidae) live horses, asses, mules, and hinnies.	Horses et al.
A2000	Live bovine animals	Live bovine animals class include cattle buffaloes (e.g., water buffaloes), bisons and hybrids (e.g., Beefalo).	Bovine animal
A3000	Live swine	The live swine class covers the live swine domestic species and live swine wild species.	Swine and poultries / monogastrics
A4100	Live sheep	The live sheep class include ewes/ewe lambs breeding females and other sheep (such as lambs and rams) that are domesticated animals.	Sheep and goats
A4200	Live goats	The live goats class include female breeding goats and other goats.	Sheep and goats
A5000	Live poultry	The live poultry class refers to domestic birds which are intended for feather, meat and egg production. Following animals are included in this class: Domestic hens and chickens; turkeys; ducks; domestic geese; quails; pheasants; guinea fowl; pigeons and ostriches.	Swine and poultries / monogastrics

Appendix Table 3 Overview of Eurostat data: Soil cover by NUTS2 regions (Eurostat - European Commission, 2021b; Eurostat - Statistics Explained, 2020)

Eurostat abbreviation	Full name	Definition	Unit
SC_WNTCR	Normal winter crop	Normal winter crops are sown in autumn and grow in winter (e.g., winter wheat; winter rape or grass).	ha
SC_COV_INTCR	Cover crop or intermediate crop	Cover or intermediate crops are sown with the purpose to prevent soil and nutrient loss. The plants cover the soil during winter, while their economic interest is low.	ha
SC_PLRES	Plant residues	Plant residues or stubble of the previous winter season are left on the arable fields.	ha
SC_BARE	Bare soil	Arable field which has no plant residues or other vegetational cover during winter, is ploughed, or tilled during autumn and remained bare until the following seeding operation.	ha
SC_MAPL	Multi-annual plants	Multi-annual plants are sown and cultivated during several years and contribute to a permanent soil cover.	ha

Appendix Table 4: **Overview of Eurostat data: Tillage on arable fields** (Eurostat - European Commission, 2021c; Eurostat: Statistics Explained, 2019f)

Eurostat abbreviation	Full name	Definition	Unit
TIL_CV	Conventional tillage	Conventional tillage means the agricultural treatment of arable land where the soil is inverted with agricultural machineries (such as mouldboard or disc plough).	ha
TIL_CSERV	Conservational tillage	Conservational tillage describes the treatment of soil by low (conservational) tillage, where plant residues (at least 30%) are left on the soil surface. This tillage practice contains strip or zonal tillage; tined or vertical tillage and ridge tillage.	ha
TIL_ZERO	Zero tillage	Zero tillage is defined as no tillage applied on the arable land between the harvest and sowing period.	ha

Appendix Table 5 : Bioclimatic data from worldclim (Fick and Hijmans, 2017)

World clim abbreviation	Full name	Unit
BIO1	Annual Mean Temperature	C°
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	C°
BIO3	Isothermality (BIO2/BIO7) (×100)	%
BIO4	Temperature Seasonality (standard deviation ×100)	%
BIO5	Max Temperature of Warmest Month	C°
BIO6	Min Temperature of Coldest Month	C°
BIO7	Temperature Annual Range (BIO5-BIO6)	C°
BIO8	Mean Temperature of Wettest Quarter	C°
BIO9	Mean Temperature of Driest Quarter	C°
BIO10	Mean Temperature of Warmest Quarter	C°
BIO11	Mean Temperature of Coldest Quarter	C°
BIO12	Annual Precipitation	mm
BIO13	Precipitation of Wettest Month	mm
BIO14	Precipitation of Driest Month	mm
BIO15	Precipitation Seasonality (Coefficient of Variation)	mm
BIO16	Precipitation of Wettest Quarter	mm
BIO17	Precipitation of Driest Quarter	mm
BIO18	Precipitation of Warmest Quarter	mm
BIO19	Precipitation of Coldest Quarter	mm

Appendix Table 6 : Overview: Agricultural landscape classification regarding crop and livestock activities

Class	NUTS area (total number)	Share of UAA [5]	Dominant cropping system[6]	Additional cropping system[7]	Diversity in the cropping system[8]	Intensity[9]	Dominant livestock system (median LSU/ha)[10]	Diversity in the livestock system[8]	Final class label[11]
1	AT12, AT13, CZ02, CZ04, CZ06, CZ07, DE4, DE8, DED, DEE, DEG, FR24, PL51, PL52, SE22 (15)	46%	**Industrial crops (I0000):** Oilseeds (I1100); Aromatic, medicinal and culinary plants (I5000); **Root crops (R0000):** Sugar beet (R2000)	Cereals (C0000): Cereals for the production of grain (C1110); Durum wheat (C1120); Rye and winter cereal mixtures (C1200); Triticale; Sorghum; Other cereals (C1600_1700_1900)	high	extensive		low	*Mixed* cropping system of dominant industrial, and root crops

[5] The column describes the share of UAA from the total area in percentage in which the median has been used to summarize the values of the respective NUTS regions.
[6] Each main crop-tree category is considered that exceed the third quartile of all class values
[7] The 'Additional cropping system' covers the subcategories of crop-tree types which have been used beforehand in the LPA for structuring the classes. Partially, some crop-tree subcategories also exceed the third quartile which is considered in the further classification but does not contribute to the final class labeling due to its limited significance .
[8] Diversity in the cropping and the livestock system classification is based on the Shannon-Weaver diversity index in which results are defined by tertiles division.
[9] Intensity is based on the quantiles distribution with respect to the total LSU per area where "extensive" systems are those that remain below the first quartile and "intensive" systems are those that surpass the third quartile. The values between these thresholds therefore do not receive any further specification of the intensity in livestock.
[10] The 'Dominant livestock system' summarizes the livestock animals which exceeded the third quartiles. Although a value of intensity was previously assigned to classes, some classes occur to not have a livestock category which is above the third quartile, thus will not be considered. However, this leads to the fact that some classes have been attributed an intensity, but the livestock system, depending on the definition set before, is not mentioned because of their assumed lower effect on the class in general
[11] Accordingly, the final class label is mainly derived by following columns: (i) 'Dominant cropping system'; (ii) 'Diversity in the cropping system'; (iii) Intensity; (iv) 'Dominant livestock system' and (v) 'Diversity in the livestock system'.

Class	NUTS area	Share of UAA	Dominant cropping system	Additional cropping system	Diversity in the cropping system	Intensity	Dominant livestock system	Diversity in the livestock system	Final class label
2	CZ01, DK02, FR10, FR21, FR22, FR23, UKE1, UKE3, UKH1 (9)	61%	**Cereals (C0000):** Cereals for the production of grain (C1110); Barley (C1300); Grain maize and corn-cob-mix (C1500); **Industrial crops (I0000):** Aromatic, medicinal and culinary plants (I500); Other industrial crops (I9000); Oilseeds (I1100); Fibre crops (I2000); **Root crops** (R0000): Potatoes (R1000); Sugar beet (R2000); **Dry pulses and protein crops** (P0000)		medium	extensive		medium	Cropping system of dominant cereals, pulses, industrial, and root crops
3	AT22, FR42, FR61, HR04, ITC1, ITC4, ITH3, ITH4, RO11, RO21, RO42, SI01 (12)	39%		Permanent crops (PECR): Fruits, berries and nuts (F0000); Grapes (W1000)	low		Monogastric (swine and poultry) and horses (et al.)	high	*Mixed* livestock system of dominant monogastric, and horses (et al.)

Class	NUTS area	Share of UAA	Dominant cropping system	Additional cropping system	Diversity in the cropping system	Intensity	Dominant livestock system	Diversity in the livestock system	Final class label
4	BE10, BE31, BE32, BE33, FR30, NL34 (6)	46%	**Root crops (R0000):** Potatoes (R1000); Sugar beet (R2000); Other root crops (R9000); **Fresh vegetables and strawberries (V0000_S0000)**	Cereals (C0000): Cereals for the production of grain (C1110); Industrial crops (I0000): Fibre crops (I2000); Other industrial crops (I9000)	high	extensive	Bovine	low	*Mixed* cropping system of dominant root crops, and vegetables with an extensive bovine livestock system
5	BE22, BE23, BE24, BE25, MT00, NL11, NL13, NL23, NL32, NL33, NL42 (11)	44%	**Root crops (R0000):** Potatoes (R1000); Sugar beet (R2000); **Fresh vegetables and strawberries (V0000_S0000); Plants harvested green (G0000)**	Industrial crops (I0000): Fibre crops (I2000)	medium	intensive	Bovine, monogastric (swine, poultry), goats and horses (et al.)	medium	Cropping system of dominant root crops, vegetables, and grasses with an intensive livestock system of dominant monogastric, bovine, goats, and horses (et al.)
6	AT31, BE35, CZ03, CZ05, CZ08, DE1, DE2, DE7, DE9, DEA, DEB, DEC, DEF, EL13, ES22, ES24, ES30,	44%		Cereals (C0000): Durum wheat (C1120); Rye and winter cereal mixtures (C1200); Grain maize and corn-cob-mix (C1500); Triticale; Sorghum; Other cereals (C1600_1700_1900)	low		Bovine	low	Bovine livestock system

FI20,
FR25,
FR26,
FR41,
FR43,
FR51,
FR52,
FR62,
FR63,
FR71,
FR72,
ITH5,
LU00,
LV00,
PL21,
PL32,
SE21,
SK03,
SK04,
UKK1
(37)

Class	NUTS area	Share of UAA	Dominant cropping system	Additional cropping system	Diversity in the cropping system	Intensity	Dominant livestock system	Diversity in the livestock system	Final class label
7	AT11, BG31, BG32, BG33, BG34, FR53, HU10, HU21, HU22, HU23, HU31, HU32, HU33, RO22, RO31, RO32, RO41, SK01, SK02 (19)	50%	**Cereals (C0000):** Cereals for the production of grain (C1110); Durum wheat (C1120); Grain maize and corn-cob-mix (C1500); Triticale; Sorghum; Other cereals (C1600_1700_1900); **Industrial crops** (I0000): Tobacco (I3000); Oilseeds (I1100)		medium		Poultry	high	*Mixed* farming system of dominant cereals, and industrial crops in the cropping system with a dominant poultry livestock system
8	AT21, AT32, AT33, AT34, BE34, BG41, EL21, EL42, ES11, ES12, ES43, FR83, HR03, IE01, ITC2 ITG2, ITH1,	41%	Permanent grassland (J0000)	Cereals (C0000): Triticale; Sorghum; Other cereals (C1600_1700_1900)	low		Bovine, swine and goats	low	Cropping system of permanent grassland with a bovine livestock system

	ITH2, PT18, PT20, RO12, SI02, UKD1, UKM3, UKM6, UKN0 (26)							
9	BG42, EL11, EL12, ITF3, ITI2 (5)	36%	**Industrial crops (I0000):** Tobacco (I3000); Aromatic, medicinal and culinary plants (I5000); Oilseeds (I1100) **Permanent crops (PECR):** Olives (O1000); Fruits, berries and nuts (F0000); Grapes (W1000)	Cereals (C0000): Durum wheat (C1120)	medium	Sheep	high	*Mixed* farming system of dominant industrial, and permanent crops in the cropping system with a dominant sheep livestock system

Class	NUTS area	Share of UAA	Dominant cropping system	Additional cropping system	Diversity in the cropping system	Intensity	Dominant livestock system	Diversity in the livestock system	Final class label
10	CY00, EL14, ES23, ES42, ES51, ES52, ES62, FR81, FR82, ITF1, ITI1, ITI4, PT11, PT15, PT16, PT17 (16)	31%	**Permanent crops (PECR):** Fruit, berries and nuts (F0000); Other permanent crops (PECR9_H9000); (T0000); Olives (O1000); Grapes (W1000)	Cereals (C0000): Durum wheat (C1120)	medium		Sheep and goats	high	*Mixed* farming system of dominant permanent crops in the cropping system with a dominant sheep, and goat livestock system
11	DE5, DE6, ES13, ES21, SE11, UKD3 (6)	25%	**Permanent grassland (J0000)**		low		Bovine and horses (et al.)	low	Cropping system of permanent grassland with a dominant bovine and horses (et al.) livestock system
12	DK01, DK03, DK04, DK05, ES53 (5)	52%	**Cereals (C0000):** Rye and winter cereal mixtures (C1200); Barley (C1300); Oats and spring cereal mixtures (C1400); **Plants harvested green (G0000)**	Permanent crops (PECR): Other permanent crops (PECR9_H9000)	high	intensive	Swine and horses (et al.)	low	*Mixed* cropping system of dominant cereals, and grasses with an intensive dominant swine, and horses (et al.) livestock system

Class	NUTS area	Share of UAA	Dominant cropping system	Additional cropping system	Diversity in the cropping system	Intensity	Dominant livestock system	Diversity in the livestock system	Final class label
13	EE00, ES41, LT00, UKD7, UKE3, UKF2, UKG3, UKH2, UKH3, UKJ1, UKJ3, UKJ4 (12)	48%	**Industrial crops (I0000):** Oilseeds (I1100); **Dry pulses and protein crops** (P0000)	Cereals (C0000): Cereals for the production of grain (C1110); Barley (C1300); Oats and spring cereal mixtures (C1400)	medium	intensive	Sheep and horses (et al.)	high	*Mixed* farming system of dominant industrial crops, and pulses in the cropping system with an intensive dominant sheep and horses (et al.) livestock system
14	EL22, EL23, EL24, EL25, EL30, EL41, EL43, EL61, ITF6 (9)	43%	**Permanent crops (PECR):** Fruit, berries and nuts (F0000); Other permanent crops (PECR9_H9000); (T0000); Olives (O1000); Grapes (W1000); **Fresh vegetables and strawberries (V0000_S0000); Permanent grassland (J0000)**		low		Sheep and goats	high	Cropping system of permanent crops, vegetables, and permanent grassland with a *mixed* livestock system of dominant sheep and goats
15	FI19, FI1B, FI1C, SE12, SE23 (5)	17%	**Cereals (C0000):** Rye and winter cereal mixtures (C1200); Barley (C1300); Oats and spring cereal mixtures (C1400); **Dry pulses and protein crops (P0000); Plants harvested green (G0000)**	Industrial crops (I0000): Aromatic, medicinal and culinary plants (I5000); Fibre crops (I2000)	high	extensive	Swine	medium	*Mixed* farming system of dominant cereals, pulses, and grasses in the cropping system with a dominant extensive swine livestock system

Class	NUTS area	Share of UAA	Dominant cropping system	Additional cropping system	Diversity in the cropping system	Intensity	Dominant livestock system	Diversity in the livestock system	Final class label
16	ITF2, ITF4, ITF5, ITG1, ITI3 (5)	51%	**Permanent crops (PECR):** Fruit, berries and nuts (F0000); Other permanent crops (PECR9_H9000); (T0000); Olives (O1000); Grapes (W1000); Dry pulses and protein crops (P0000); **Fresh vegetables and strawberries (V0000_S0000); Plants harvested green (G0000)**	Cereals (C0000): Durum wheat (C1120); Oats and spring cereal mixtures (C1400)	high	extensive		medium	*Mixed* farming system of dominant vegetables, grasses, and permanent crops in the cropping system
17	IE02, UKC1, UKC2, UKD4, UKD6, UKE2, UKE4, UKF1, UKG1, UKG2, UKJ2, UKK2, UKK3, UKK4, UKL1, UKL2, UKM2, UKM5 (18)	70%	**Permanent grassland (J0000)**	Root crops (R0000): Other root crops (R9000)	low	intensive	Sheep and horses (et al.)	medium	Cropping system of permanent grassland with an intensive livestock system of dominant sheep and horses (et al.)

Class	NUTS area	Share of UAA	Dominant cropping system	Additional cropping system	Diversity in the cropping system	Intensity	Dominant livestock system	Diversity in the livestock system	Final class label
18	BE21, NL12, NL21, NL22, NL31, NL41 (6)	44%	**Root crops (R0000):** Potatoes (R1000); Sugar beet (R2000); **Plants harvested green (G0000); Permanent grassland (J0000)**	Industrial: Fibre crops (I2000)	low	intensive	Bovine, monogastric (swine and poultry), horses (et al.)	medium	Cropping system of root crops, grasses, and permanent grassland with an intensive livestock system of dominant bovine, monogastric, and horses (et al.)
19	PL11, PL12, PL22, PL31, PL33, PL34, PL41, PL42, PL43, PL61, PL62, PL63 (12)	46%	**Cereals (C0000):** Rye and winter cereal mixtures (C1200); Oats and spring cereal mixtures (C1400); Grain maize and corn-cob-mix (C1500); Triticale; Sorghum; Other cereals (C1600_1700_1900); **Dry pulses and protein crops (P0000); Fresh vegetables and strawberries (V0000_S0000)**	Industrial crops (I0000): Tobacco (I3000); Other industrial crops (I9000); Permanent crops (PECR): Other permanent crops (PECR9_H9000); Root crops (R0000): Potatoes (R1000)	high		Monogastric (swine and poultry)	low	*Mixed* cropping system of dominant cereals, pulses, and vegetables with a dominant monogastric livestock system