D3.1

Report on current and future livestock systems

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[1] Document, report (R), Demonstrator, pilot, prototype (DEM), Websites, patent filings, videos, etc., OTHER, Ethics requirement (ETHICS), Open Research Data Pilot (ORDP), Data sets, microdata, etc. (DATA)
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Executive Summary

Deliverable 3.1 characterises current and future European livestock systems at the farm or enterprise level. This task was led by Aberystwyth University (ABER) and the Research Institute of Organic Agriculture (FiBL), with contributions from many partners from within and beyond the project.

The first phase in the task aimed to **characterise current European livestock production systems** for cattle, pig, poultry and small ruminants at farm level, and an initial characterisation was reported within the **Milestone 11** report "*Initial characterisation of European livestock*". The challenge was how to build a representative typology of livestock production systems at European level, including key information about sustainability. After reviewing existing characterisation of livestock systems, a new approach was developed to utilise both quantitative and qualitative data. Firstly, as key information sources, the European Eurostat and FADN databases were explored, and general livestock systems identified at European level through clustering. Hierarchical clustering based on a principal component (HCPC) analysis conducted in R identified clusters for each livestock category. These clusters were statistically assessed as well as manually checked for likelihood. This process had limitations due to the specifics of each dataset, e.g. FADN farm typology groups all monogastric species in one farm type due to small sample sizes but cross-referencing between the more detailed Eurostat data allowed an improved clustering for specific livestock classes within the FADN data.

Secondly, a survey with quantitative and qualitative indicators was created to collect information about the livestock systems of each European country from the PATHWAYS partners and other experts. It was designed to capture general information, but more importantly, many aspects absent from the databases, such as specific information regarding rations, grazing access, physical productivity KPIs and more. In total 56 responses were received, detailing 171 system specifications, which were subsequently supported by expert interview findings.

Finally, the three database cluster classes were merged at NUTS2 level to identify regions with common and unique attributes. This was then manually cross-checked with the survey data and typical systems were identified across all relevant regions, i.e. individual merge classes were grouped to a reduced number of final system types. As a final step, the identified systems were presented as posters at the PATHWAYS annual meeting in 2023 for validation by participants. The final selection of systems forms the basis of the defined systems presented in this report and summarised in Figure 1, overleaf. This system inventory will be used in subsequent tasks within the project to analyse selected systems through holistic LCA approaches to ensure a good representation of the diversity of livestock systems in Europe.

The second phase of the task was to **develop and characterise future livestock systems** for all sectors. Workshops within WP2 created multiple 'storylines' for use within the project and Task 3.1 interpreted these to develop possible future farm system scenarios for each sector. Three of the storylines were most appropriate for livestock farm level scenarios, including Efficiency First (EF), Feed no Food (FnF) and High

Animal Welfare (HAW), with two further storylines not pursued as they either eliminated livestock production (Stockless), or were aimed at regional socio-economic changes (Rural Renaissance), so were less suited for environmental LCA assessment.

Whilst the WP2 workshops to develop the storylines provided outlines of objectives for future systems, precise sector level details were not prescribed. Therefore, a process of researching information from literature, industry guides and experts was undertaken and reflected upon to develop the sector scenarios. Within the EF storyline, all sectors were further intensified, with assumptions around improved feeding, breeding, housing and emission control, leading to increased productivity and improved feed conversion efficiencies. The FnF storyline caused the least changes to the extensive ruminant sector but system redesign for the intensive monogastric sector. Due to the exclusion of grains and pulses for livestock broiler production was assumed to be discontinued. The HAW storyline was more diverse, and whilst the intensity of the livestock sector would be significantly reduced compared to EF, all sectors could continue to operate. For each sector, specific changes and the baseline systems utilised were identified and described, providing a characterisation for use in subsequent analysis within Pathways and ultimately available as a dataset for use beyond the project.

Overall, whilst meeting the aims of the task, this analysis also highlighted the difficulties in achieving a livestock classification for the whole of Europe. Limitations within the data sources, whether that is fine detail missing from Europe-wide official databases, or lack of coverage when using case study literature or conducting interviews about regional or specific systems, all contribute to difficulty generating a consistent characterisation. However, this report and the subsequent lifecycle and economic analysis through WP5 will provide a comprehensive analysis of current and future systems under varying storyline assumptions, enabling the development of transition pathways for the European livestock sector.

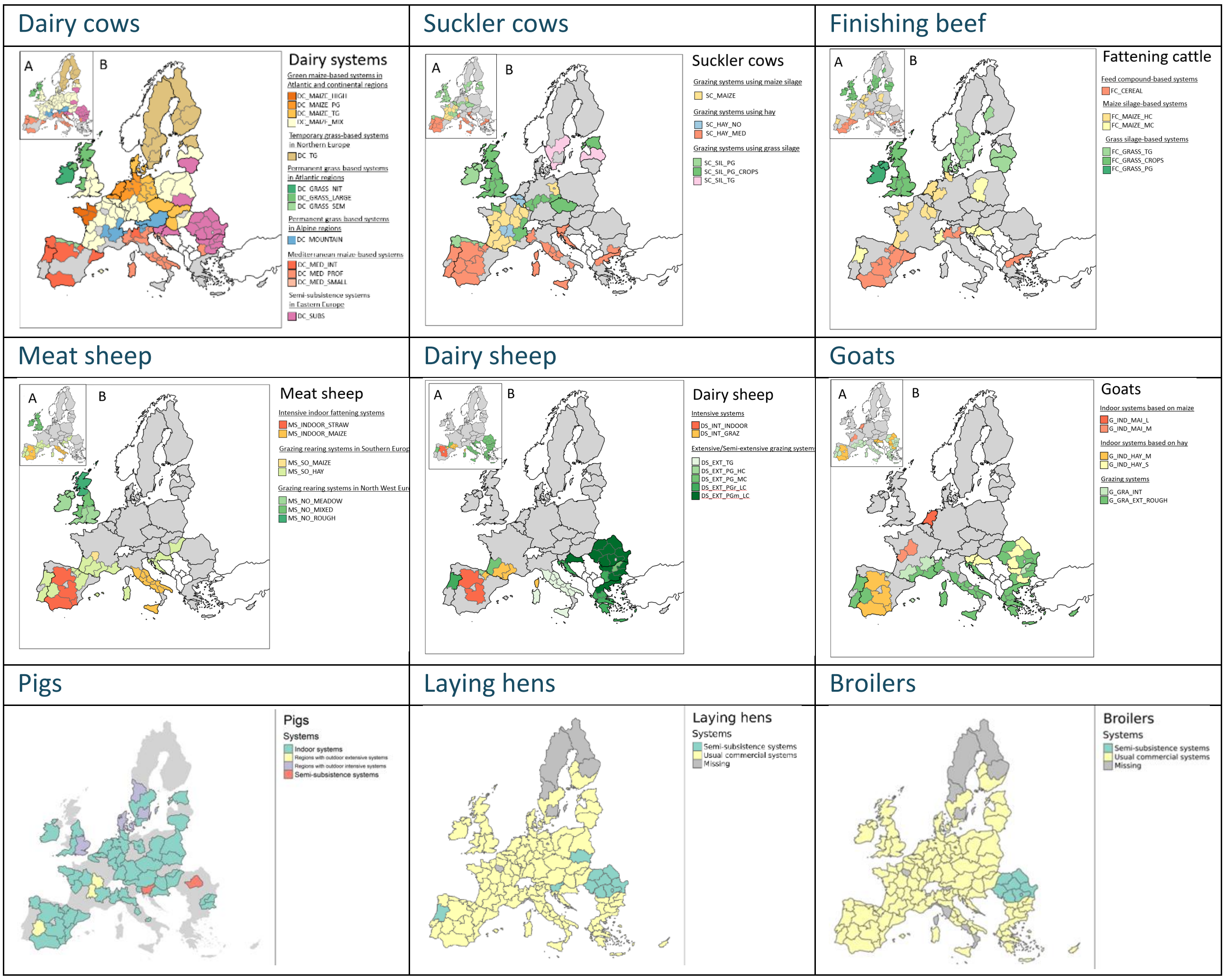

Figure 1 Defined baseline systems per livestock class (full size figures provided in each sector section) Note: For poultry, the Eurostat and FADN databases were unable to differentiate between systems, except for commercial and semi-subsistence systems, therefore survey data is more relevant.

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Maps:
All maps were created by Eléa Bailly-Caumette using R software

Introduction

Worldwide, livestock production is increasingly criticised because of its important environmental impacts (Steinfeld & Gerber, 2010), its competition with human food through feed that could be directly consumed by humans (Barbieri et al., 2022) and its ethical issues (Hocquette, 2023). At the same time, livestock production systems have been shown to provide high quality protein from low quality biomass (Hennessy et al., 2021) and to also fulfil a wide range of ecosystem services, from climate mitigation to biodiversity preservation (Franzluebbers & Martin, 2022). In the context of the European Green Deal, it is crucial to determine what sustainable livestock systems of the future could look like. In this way, through a holistic approach, the European PATHWAYS project aims to identify the sustainable practices that should be enhanced and to model the evolution of the European livestock systems for a more sustainable future. Therefore, in a first step, existing systems should be identified and characterised, before potential future system scenarios can be developed based on PATHWAYS storylines.

Baseline system development

SYSTEM DEFINITION: FARM OR FARMING SYSTEM?

A system can be defined as 'a group of parts (subsystems) that are interacting according to some kind of process' (Odum, 1983). A system is composed of five elements: the boundaries, the inputs, the outputs, the subsystems and the internal structures - how the subsystems interact (Giller, 2013). Despite the diversity of studies about farm and farming systems, no clear and common definition has been given (Giller, 2013). A farm system can be described as the combination of 'the household, its resources and the resource flows and interactions at the individual farm level' (Dixon et al., 2001). The boundary of the system is usually the farm and its utilised agricultural area (Giller, 2013). The subsystems of a farm system are the primary food production systems with all the agricultural activities and the other activities such as on-farm tourism, catering, processing or retail (Pfeifer et al., 2022). For simplifications, this study only considered the primary food production system. At larger scale, a farming system is a network of individual farms that represent a similar production system with equal resources and enterprises, that are interacting and that are in the same geographical, environmental and socio-economic context (Cochet, 2012; Dixon et al., 2001; Meuwissen et al., 2019; Pfeifer et al., 2022).

In this study, a livestock production system has been defined as a farm system with livestock. This definition encompasses the enterprises of the system (land use and livestock), their interactions, their inputs (e.g. fertilisers, pesticides, feed, purchased animals, buildings) and their outputs (e.g. products, services).

Within the PATHWAYS project, to understand the existing contribution and impact of the diverse types and systems of livestock agriculture, current livestock production systems need to be characterised at European level for each type of production (cattle, small ruminants, pigs and poultry). These system specifications will then be subsequently assessed to generate indicators (KPIs) that can provide key information for sustainability assessment (i.e. covering environmental, social and economic dimensions).

THE EXISTING CHARACTERISATION OF LIVESTOCK SYSTEMS

A literature search highlighted that typologies of livestock production systems have already been undertaken for the different livestock sectors (
Table 1). The After 2050 scenario (Couturier et al., 2016) modelled the evolution of the French livestock production systems which would be needed to reach the objective of carbon neutrality in 2050. In this study, the classification of the current livestock production systems was based on technical and practice characteristics (milk yield, grazing time, amount of concentrate, indoor/free-range, conventional/organic/extensive, …). However, the technical characteristics are limited (between 4 and 6 per sector) and the typology was only implemented at national level.
At European level, the characterisations are mostly based on the European databases Eurostat (European Union, 2025) and FADN (European Commission, 2025). In the project "The environmental impact of dairy production in the EU" (CEAS & The European Forum on Nature Conservation and Pastoralism, 2000), the characterisation of European dairy systems was undertaken in some detail at regional level thanks to geographical, land use and economic data from Eurostat. In the GenTORE project (INRAe, 2022), the European beef and dairy systems were classified using individual FADN data according to their geographical region, the stocking density and the proportion of concentrate or grass from permanent grasslands in the feed.

Although these characterisations were undertaken at European level and linked to the geographical location, they only included one species (bovine). Moreover, the use of European databases provides economic data but is limited regarding technical data at farm level linked to sustainability (Kelly et al., 2018). Finally, in Dumont et al. (2019), the typology of European livestock territories combined mapping based on Eurostat data and a representation of the bundle of services and impacts provided by livestock in some territories with the Barn representation, "La Grange" in French. The originality of this typology is the combination of quantitative data at European level and qualitative data at territory level. However, the

European map does not differentiate between the different production types, and the Barn representation is commonly used to illustrate a territory and not a farm type as needed in PATHWAYS.

Table 1 Previous characterisation of livestock production systems and comparison with the objectives of the project

Characterisation	Geographic scale	System scale	Production focus	Basis
(CEAS & The European Forum on Nature Conservation and Pastoralism, 2000)	Europe	Regional level	Dairy cows	Eurostat data, geographically based
Afterre 2050, (Couturier et al., 2016)	France	Farm system	All production	Technical characteristics and scenarios
(INRAe, 2022)	Europe	Farm system	Beef and dairy	FADN data, geographically based
ESCO (Dumont et al., 2019)	Europe	Territorial level	All production together	Maps based on Eurostat data and La Grange representation
Objectives of PATHWAYS	Europe	Farm system at regional level	Each production system	Technical characteristics linked to sustainability as well as data from Eurostat and FADN database

Future system development

Identifying and characterising future livestock systems is more challenging than identifying existing ones due to the lack of concrete information or detailed studies. Whilst many projects and reports discuss future systems from a food system perspective, there is often a global focus, e.g. Thornton (2010) or a lack of detail regarding the characterisation of livestock systems e.g. Singh et al. (2023). Furthermore, farms respond to policy decisions and whilst the European Green Deal can serve as a guide, there is great uncertainty due to the rapidly changing geopolitical situation (DG AGRI, 2025). Key food system philosophies emerge which can be applied to livestock systems, including efficiency, sufficiency and consistency (Allievi et al., 2015; Muller & Schader, 2017), but often the detail necessary for assessment, with, for example with LCA, is absent. Furthermore, within the food system debate, whilst it is clear that livestock cause greenhouse gas (GHG) emissions as well as other negative environmental impacts, system specific assessments are needed to avoid generalisations and identify positive attributes that could include avoiding food versus feed trade-offs (Wilkinson, 2011).

Research question and objectives of the characterisation

Regarding the scope of the Pathways project, a characterisation of both current and future European livestock production systems for cattle, pig, poultry and small ruminants was needed. The characterisation would be mainly used to identify the systems that should be further assessed through a sustainability assessment (Life Cycle Sustainability Assessment) within WP5. With this aim, indicators regarding feeding strategies, herd/flock structure, housing and land use should be used due to their impact on emissions, animal welfare and biodiversity. Furthermore, the systems should be described at European level. Therefore, the characterisation should provide information at a farm level but also encompass a regional representation to provide a relevant description at European level.

Therefore, this document describes the construction of a representative typology of livestock production systems at European level, including key information about sustainability and connecting both farm scale and regional scale. Whilst in theory the description of a livestock production system is straight forward, an integrated system or database that describes livestock systems in Europe does not exist. Therefore, a method was developed to utilise multiple information sources that combines production statistics, economic databases, and expert opinions. Subsequently, these baseline systems were adapted to represent the project storylines and specify future system scenarios using literature and other resources.

Purpose and Scope

This deliverable provides both an initial characterisation of European livestock systems and a description of future systems developed from Pathways storylines created in WP2. The baseline systems were based upon statistical and expert evidence available and provide a Europe wide perspective of frequently occurring livestock systems and farm scales. The future European livestock systems are characterised by taking these baseline systems and applying the Pathways storylines – these are then modelled and assessed in Work Package 5.

Materials and methods

Baseline systems construction

To construct the baseline systems within each sector a methodology was developed to utilise data from multiple sources. Data was sourced from Eurostat (European Union, 2025) and the Farm Accountancy Data Network (FADN, 2023) public databases and combined with an expert survey. This multi-source evidence base provided quantitative and qualitative data and as shown in Figure 2.

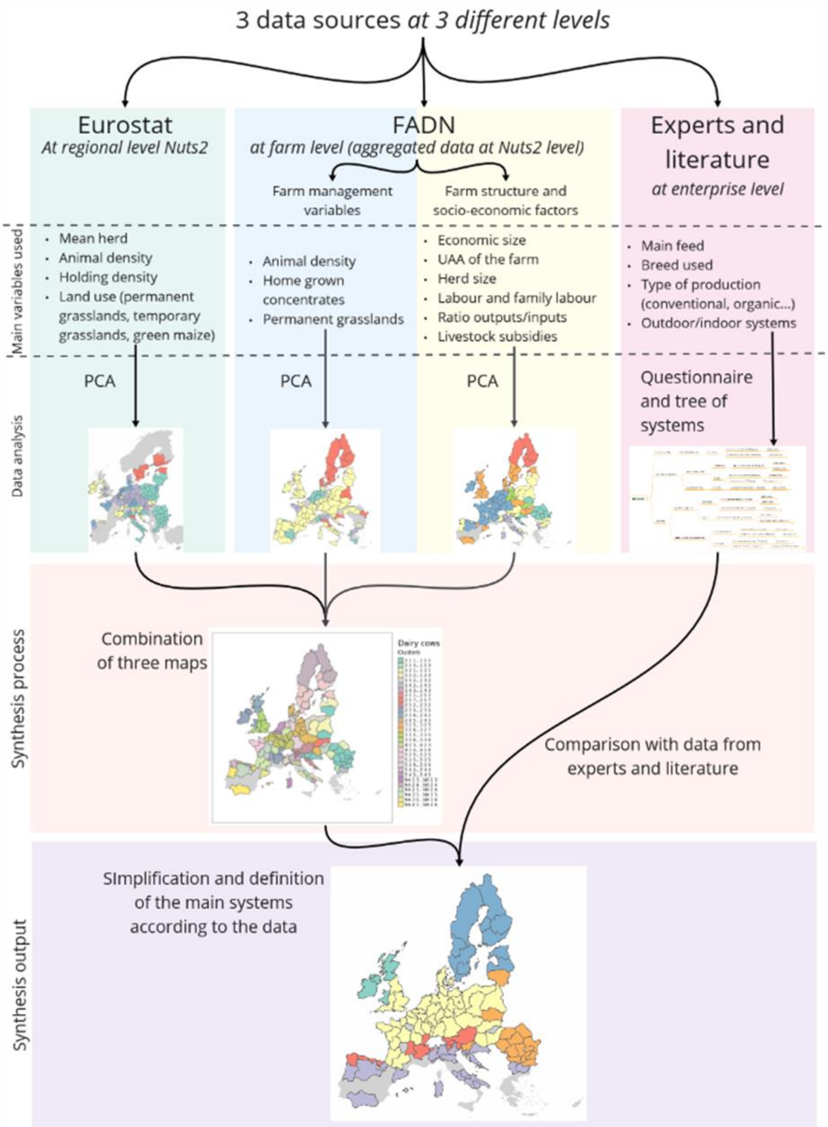

Figure 2 Scheme of the methodology developed for characterising the current European livestock production systems.

Firstly, to have an overview across Europe, Eurostat and FADN aggregated data were statistically analysed to create regional maps at NUTS2 level with a general classification of the systems for each species. In parallel, a survey was sent to PATHWAYS partners and other experts to provide an inventory of the current European livestock production systems in their country, and within their expertise. In a final step, the results of the different analysis were combined to synthesise the main livestock systems in Europe.

EUROSTAT DATA

Utilising the Eurostat dataset the objective was to explore if some common systems could be identified at regional level in the European Union for each livestock sector. Nine sectors were considered: dairy cows, beef cows, finishing beef cattle, sheep (dairy), sheep (meat), goats, pigs (breeding and finishing), laying hens and broilers. The Eurostat data from 2016 (or closest available year, e.g. 2013 for Germany) were assessed at NUTS 2 level. NUTS 2 regions were retained for further analysis if they fulfilled three criteria: (1) less than 20% of artificial land cover, (2) more than 10% of Utilised Agricultural Area (UAA) and (3) more than 0.1 Livestock Unit (LSU) per ha of UAA. This filter removed the remote islands and the densely populated urban areas from the data which were not considered relevant for the study. The thresholds were chosen after identifying the extreme values on the histogram of each variable considered.
Following construction of the dataset, a hierarchical clustering procedure based on principle components (HCPC) was conducted on each livestock category using the FactoMineR package(Husson et al., 2017). The number of clusters was graphically determined with the loss of inertia and followed up with manual checking of clusters for meaningfulness regarding the variables used. The variables used in the HCPC are shown in Table 2.

As the Eurostat data were averages at regional level, two assumptions were made. Firstly, for ruminants, it was assumed that the land use at regional level could be linked to the feed (e.g. if there was a high percentage of permanent grasslands in the region, it was assumed that ruminants in the region were grazing on permanent grasslands). Secondly, a minimum proportion of livestock was needed to link regional land use and feed, therefore only regions with a minimum percentage of total livestock and minimum livestock density per ha of UAA were considered (Table 2). For monogastric sectors, it was assumed that systems are mainly landless and therefore there was no direct link with farmland use, thus no land variables were used for monogastric clustering, and all regions were retained for the analysis. However, this was a limitation of the baseline classification using database data for monogastric livestock.
Following clustering, the results were validated through a presentation of the results visually on map posters and during a consortium meeting of the project, where partners were invited to provide feedback.

Table 2 Variables used in HCPC for each livestock category and the criteria met by the regions analysed. In orange, variables linked to the livestock only; in green, variables linked to the land use only; in blue: calculated variable using one livestock variable and one land use variable. (UAA: Utilised Agricultural Area, LSU: Livestock Unit)

Livestock category	Mean herd	Holding density	Livestock density/ha of UAA	Livestock density/ha forage areas	% dairy livestock (sheep only)	% permanent grasslands	% permanent pastures and meadows	% permanent rough grazing	% temporary grasslands and legumes	% green maize/maize silage	Criteria for the choice of the regions
Dairy cows											> 10% of dairy cows in total livestock
Beef sucklers											> 5% of beef sucklers in total livestock
Finishing cattle											> 20% of fattened cattle in total bovines and > 20 % of bovine in total livestock
Sheep											> 5% of sheep in total livestock
Goats											> 0.5 % of goats in total livestock
Pigs											All regions considered
Laying hens											All regions considered
Broilers											All regions considered

FARM ACCOUNTANCY DATA NETWORK (FADN) DATA

The second European dataset exploited to identify livestock systems was the public database of the FADN. The FADN monitors microeconomic data of farms considered as commercial due to their economic size (FADN, 2023), and aggregates individual farm data per economic farm type at NUTS 2 level to provide an average farm data for a region (with a minimum sample size of 15 farms).

The FADN economic farm types with livestock considered were: “Specialist dairy farm”, “Specialist cattle-rearing and fattening”, “Specialist sheep and goats”, “Specialist granivores”, “Mixed livestock” and “Mixed crops and livestock”. For each livestock farm type, two types of variables were analysed: Variables linked to the management practices (practices) and variables linked to the economy and the labour (socio-economic).

For the variables linked to the practices, four were chosen: production (such as milk yield (kg/cow)), when this was available; livestock density (LSU/ha UAA); percentage of home-grown concentrates (%) and percentage of permanent grasslands (%). For the socio-economic variables, seven were chosen: economic size of the farms (,000 euros); Utilised Agricultural Area of the farm (ha); number of livestock of the category considered (LSU); labour (AWU/total LSU); proportion of family labour (%); livestock subsidies (euros/LSU) and the ratio total output (without subsidies)/total input.

Following construction of the dataset, livestock systems were identified by applying the same HCPC method used for the analysis of the Eurostat data, generating clusters linked to the FADN practise data and clusters linked to the socio- economic data.

EXPERT INFORMANTS AND LITERATURE SOURCES

Whilst the large European datasets provided a statistical overview of livestock systems, to ensure a more robust identification of systems and their characteristics, an expert survey was developed to complement this data. The survey aimed to identify specific details at a livestock enterprise level (the linked forage or cropping enterprises were only addressed to a limited extent), and the survey was constructed from expert knowledge (ABER and FiBL) and after feedback from partners (Innovationscenter Økologisk Landburg and IDDRI), with an example of the survey for the dairy sector in *Appendix 2 Expert survey*. The same livestock categories were considered, and the survey was divided into four main sections: (1) general information about the farm system (country, lowland or less favoured areas, production method (conventional or organic), estimation of proportion of livestock in this system at national level, FADN farm type and subtype), (2) free text answers for general description of the system (e.g. extensive/intensive, traditional/innovative, family or paid labour), the geographical location of the system, the perceived sustainability of the system in terms of economics, environmental and social issues, animal welfare and biodiversity positives and negatives of this system, (3) indicators about the land management (e.g. land use, crop diversity, use of fertilisers and pesticides) and (4) specific indicators about the livestock enterprise considered (e.g. for dairy cows: main breed type, size of the herd, milk yield, productive lifespan, 1st calving age, grazing days, main forage in summer and in winter).

The survey was completed by a combination of PATHWAYS' project partners, other experts and supporting literature (Table 3), with all meetings and data collation conducted by Eléa Bailly-Caumette (FiBL). From the data collected through the survey, a tree of systems for each livestock category was built with the online software Mindomo (Expert Software Applications Srl, Romania). The construction of the trees was based on expert knowledge, known classifications (e.g. French egg code for laying hens systems) and decision trees from previous projects (CEAS and GENTORE for ruminants). For sheep, in addition to dairy ewes and meat ewes, a third category "Lamb fattening" was added, which was not in the survey, as these finishing systems became apparent during the data collection process.

Table 3 Sources of the data collected per country for the survey on current European livestock production systems

Country	PATHWAYS partners	Other experts	Information/Literature sources
Croatia		University of Podua	
Denmark	ICOEL	Aarhus University	(Nielsen et al., 2021) The Danish Agency of Agriculture, 2020)
France	ACTA (IFIP, ITAVI, IDELE), IDDRI		
Germany	FiBL		www.thuenen.de
Ireland	ABER		www.teagasc.ie
Italy	UNIPI		
Netherlands	WUR, FiBL		agrimatie.nl/ www.wroetvarken.nl
Poland	IUNG, FiBL		(Barbin & You, 2009)
Romania	USAMVCN		
Spain	CSIC	NANTA	
Sweden	SLU, Naturbeteskött		
UK	ABER, Pasture For Life		(Moakes et al., 2015) www.soilassociation.org www.communitysupportedagriculture.org.uk www.porkprovenance.co.uk (Leinonen et al., 2012) (Lima et al., 2019) (NFU, 2018)

SYNTHESIS OF BASELINE SYSTEMS

The aims of the synthesis were two-fold. Firstly, to bring together the various classification of systems from the different sources (Eurostat, FADN and the survey) in a simple way, whilst secondly, reaching a compromise between limiting the number of systems defined and preserving the diversity of European livestock systems (Figure 1).

Firstly, due to discrepancies between the exact NUTS classifications used by the respective databases, the Eurostat cluster map was transformed to fit the FADN map by area weighted means. Secondly, the three maps (clusters from Eurostat, FADN practices and FADN socio-economic variables) were combined so that each region was defined by three numbers corresponding to each clustering. Then, each combination was described according to the variables used in the HCPCs including the location of the regions concerned. These descriptions were then manually linked to one or more systems described in the survey. Sometimes, to allocate regions more precisely, further data checks were made using FADN and Eurostat databases and/or additional literature. At the end of the process, a European map was created with the regions coloured according to the system defined (presented as synthesis maps in the following results section).

Future system development

Building on the baseline systems described in the previous section, the next step was to apply the PATHWAYS storylines to them to develop future livestock systems.

STORYLINES

Three future storylines were applied to the baseline European livestock systems (representing all major production systems and species). A fourth and fifth storyline were also identified within PATHWAYS - the fourth storyline “Rural Renaissance” included mainly regional socio-economic aspects, rather than livestock system changes, whilst the fifth storyline “Stockless”, was based on a Europe free of without livestock production. Neither storyline was included due to a lack of relevance to livestock production methods at a farm level.

The selected storylines were developed through a series of workshops within the Pathways project, described in Campos Gonzales et al. (In preparation). The finalised storylines ranged from technically efficient intensification, avoidance of food as feed and adapted husbandry to support animal welfare. A brief description of each storyline follows, with more detail available in the supplementary material of Campos Gonzales et al. (In preparation):

Efficiency First (EF)

This storyline builds upon the principles of sustainable intensification and emphasises productivity with the adoption of technology including precision agriculture. The concept assumes increasing specialisation with input industry consolidation and concentration to achieve lower emissions per kilogram of product. These objectives override improving animal welfare beyond current standards. To achieve the maximum efficiency, most livestock are housed, and productivity maximised through high input feeding. Monogastric systems are favoured due to their better feed conversion ratios, with traditional ruminant systems only remaining in marginal areas linked to landscape conservation. Farms are likely to become more reliant on external inputs including feed and fertilisers, though intensification, freeing up land for conservation purposes.

Feed no Food (FnF)

This storyline envisages livestock systems that promote agrobiodiversity whilst minimising competition between humans and livestock for human edible feedstuffs, such as grains and pulses. However, some crops can be used for both, such as oilseeds, producing oil as food and residues as high value feeds. Therefore, use of human inedible feed sources, such as forages produced on permanent grassland areas or as part of fertility building phases within crop rotations, in addition to food byproducts (such as oilseed cakes) should be prioritised, and only small quantities of “food” are allowed to be fed. The area of permanent grassland should be maintained, whilst there is increasing integration of grassland into cropland rotations at a 20% requirement for soil health and fertility building, though forages such as maize silage would be avoided. Soybean imports to Europe for animal production are eliminated, and whilst byproducts can be utilised, intensive systems such as pig and poultry are likely to substantially reduce in production volume, whilst more extensive ruminant systems will be likely unchanged.

High Animal Welfare (HAW)

Within the AW scenario, the welfare of livestock is prioritised and systems become more extensive. Rearing systems are re-designed to more closely reflect natural systems in terms of diet and housing including access to the outdoors. Overall, stocking densities are likely to reduce, with building space requirements increasing, and should include for example, rooting areas for pigs, as well as deep bedding and enrichment materials. Systems should include natural rearing such as cow-calf dairy and piglets should be weaned at an appropriate age, whilst breeding and rearing should be on-farm as much as possible to avoid transport and improve adaptation. Breed selection should adopt slower growing, multi-purpose animal types that provide greater resilience. Overall, existing extensive ruminant systems are unlikely to be affected by these changes, whilst more intensive monogastric and ruminant systems require radical a transformation from current systems.

CHOICE OF BASELINE SYSTEM AND RE-CHARACTERISATION

For each sector the storylines were interpreted to develop scenario farm systems. The first step was to select a current system as a baseline for adaptation, and this was undertaken based on the intensity of the baseline and characteristics of the storyline to be applied. For example, for an EF scenario an intensive baseline system would be selected, whereas for an AW scenario a more extensive baseline would be selected. Following baseline system selection, characteristics of the system were adapted according to the applied storyline to characterise a scenario system.

Land management changes

The first step in re-characterisation was to adjust land use productivity and management inputs to define the crops and forages grown, the yield level and the inputs required. This also included adaptations to management, such as changes in cutting frequency or tillage, as specified in crop and forage management. The main changes to forage and crop production for each storyline are described below and summarised in Table 4.

Cropping land

The land under cropping is assumed to become more productive within the EF storyline, as technology including precision breeding, pest control and AI develop. A yield increase of 25% beyond today's level is assumed (today's yield multiplied by a factor of 1.25), with a nutrient input aligned, though a 50% reduction in pesticide use was assumed through technological improvements in plant breeding and precision application. Furthermore, field losses from N are expected to reduce due to the use of inhibitors, more accurate placement and more efficient uptake, with reductions in N losses of up to 29% achievable (Akiyama et al., 2010). Losses of P are estimated to be reduced by 20% through more accurate placement, reductions in P fed to livestock and manure management strategies including liquid and solid separation (Schoumans et al., 2014). Due to intensive livestock systems within EF, straw would be left on the field as a carbon input, or utilised for bioenergy, whilst animal manures would be applied as digestates from biogas plants.

Cropping land under FnF management would be prioritised for human food production, with only cropping byproducts available for livestock feed, strongly impacting both the monogastric and intensive ruminant sectors, as both depend upon external feeds such as cereals. The FnF storyline assumes less technological improvement, with similar yields to today, though more agroecological approaches may improve soil quality leading to yield gains. Nutrient requirements are aligned on a yield basis, whilst nutrient losses would be expected to reduce through limited use of protected fertiliser products and improved uptake, leading to a 10-14% loss reduction whilst pesticide inputs are expected to decrease 15%. Straw residue management would remain similar, whilst animal manure quantities for cropland would be significantly reduced due to the loss of intensive pig and poultry residues and ruminant manures retained for use on grassland. However, the adoption of agroecological approaches was assumed to be strongly positive with increases in the use of buffer and margin strips, hedges, intercropping and a doubling in cover crop usage. The HAW scenario is expected to result in similar crop yields due to limited changes in technology and only a small reduction in pesticide inputs and no change in field losses of nutrients. The use of hedges would increase as part of animal welfare and adoption of agroforestry, though this may be more widely adopted within grassland areas.

Temporary grassland and forage

Temporary grassland and forages were assumed to achieve a 15% increase in yield under the EF storyline, due to improved breeding techniques and precision technology related to irrigation and fertilisation. Fertiliser inputs remained linked to yield, whilst pesticide use would reduce by 50%. Nutrient losses would reduce by 29% for N (Akiyama et al., 2010) and 20% for P (Schoumans et al., 2014), whilst the temporary grassland area would also see a reduction for ruminant production, due to biorefining of legumes for protein extraction and direct feeding to monogastrics.

Under FnF, temporary grassland would have similar yields to today due to only small technological improvements. Whilst the area utilised for temporary forage production may increase due to adoption of temporary leys into the expanded cropping area for human consumption, greater use of forages for pigs may counter the additional area available for ruminants. Inputs of fertiliser would be similar, whilst pesticide inputs would be 10% lower than today, with 10-14% reduction in nutrient losses. Pasture management practices such as fenceless grazing control could be adopted to reduce labour inputs, whilst agroecological features would be expanded.

Within the HAW storyline, temporary forage yields would be similar to today, with a slight reduction in pesticide inputs. Nutrient losses would remain similar, but the focus would be on improved livestock welfare, which would include additional hedges and potentially agroforestry, providing shading, act as a source of minerals and micro-nutrients as well as behavioural stimulus.

Permanent grassland

Under the EF storyline permanent grassland yields would remain similar, but technological advances, including autonomous machinery would reduce labour inputs. Existing low levels of pesticide inputs would be reduced by 50% due to precision application, but fertiliser inputs would be similar with the use of organic manures and the need to maintain high productivity (though permanent grassland legislation restricts widespread cultivation due to biodiversity loss concerns). Losses of nutrients would be reduced by 29% for N (Akiyama et al., 2010) and 20% for P (Schoumans et al., 2014) due to the use of inhibitors, injection of digestates and other measures listed above.

The FnF storyline indicates similar permanent grassland yields and nutrient inputs, but losses of N and P reduced by 10-14% and a 10% reduction in pesticide use due to precision application. Other changes would be minimal, though some grassland would now be harvested for use in protein extraction for monogastric feed, however, temporary forages would be most suited for this purpose.

The HAW storyline would have little impact on permanent grassland yields and management, with a small reduction in pesticide use, but similar nutrient inputs and losses.

Table 4 Crop, temporary and permanent grassland management changes (relative to baseline), under three PATHWAYS storylines.

Land type	Cropland			Temporary grassland			Permanent Grassland		
	EF	FnF	HAW	EF	FnF	HAW	EF	FnF	HAW
•Yield[1]	125%	100%	100%	115%	100%	100%	100%	100%	100%
•Use of technology[1]	precision breeding, remote control systems, precision irrigation, precision pesticide application, remote controlled and AI machinery, renewable energy use	Minimal technological improvements, more use of machinery	Precision livestock farming, no changes in technology	precision breeding, remote control systems, precision irrigation, precision pesticide application, remote controlled and AI machinery, renewable energy use, virtual fencing	Minimal technological improvements, improved grazing systems through both technology and management, more use of machinery	Precision livestock farming, no changes in technology	remote control systems, remote controlled and AI machinery partially implemented, renewable energy use, virtual fencing	Minimal technological improvements, improved grazing systems through both technology and management, more use of machinery	Precision livestock farming, no changes in technology
•Nutrient requirements[1]	125%	100%	100%	115%	100%	100%	100%	100%	100%
•Quantity of pesticide AI[1]	50%	85%	90%	50%	90%	90%	50%	90%	90%
N loss[1]	71%	86%	100%	71%	86%	100%	71%	86%	100%
P loss[1]	80%	90%	100%	80%	90%	100%	80%	90%	100%
•Tillage management[1]	80% min till	80% min till	No change	80% min till	80% min till	No change	N/A	N/A	N/A
•Agroecology measures[1]									
- buffer strips[1]	No	120%	No change	No	120%	No change	No	N/A	No change
- margins[1]	No	120%	No change	No	120%	No change	No	N/A	No change
- hedges[1]	No	120%	150%	No	120%	150%	No	N/A	200%
- intercropping[1]	No	200%	No change	No	N/A	No change	No	N/A	No change
- cover crops[1]	120%	200%	No change	120%	N/A	No change	N/A	N/A	No change
Residue management[1]	100% on field	No change	100% for bedding	20% of the grass will be used to extract concentrates for monogastric livestock	20% of the grass will be used to extract concentrates for monogastric livestock	0%	20% of the grass will be used to extract concentrates for monogastric livestock	20% of the grass will be used to extract concentrates for monogastric livestock	0%
Key rotations	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fertilizer management[1]	50% of animal waste is used as digestate always injected and 50% processed as fertilizer outside the farm	No animal waste available	Manure based when manure is available	50% of animal waste is used as digestate always injected and 50% processed as fertilizer outside the farm	All the animal waste is applied in temporary grassland.	Manure based when manure is available	50% of animal waste is used as digestate always injected and 50% processed as fertilizer outside the farm	0%	Manure based when manure is available
Grassland management[1]				0% grazing		More freshly collected forage	10% grazing		More freshly collected forage and grazing. Silvopasture: 10% trees
Further comments		More crop land will be used for other purposes.			Increase in temporary grassland for agroecological purposes. Grazing is optimised.		10% of grassland is used for grazing	Grazing is optimised.	

[1]Changes relative to baseline values

Livestock system specification

The second step focussed on changes in livestock productivity, the quantity and type of inputs, livestock housing and manure management.

LIVESTOCK PRODUCTIVITY

By developing future livestock systems within the proposed project storylines, it is expected that livestock productivity will change. The application of storylines with greater intensity will likely increase livestock productivity, with higher yields per animal achieved from less or similar inputs. Alternatively, more extensive storylines will likely reduce output per animal as growth times extend or yields per head reduce. The choice of breed type is specific for each production type, affecting animal liveweight, their productivity including milk yield, prolificacy and number of cycles per annum. Changes in mortality as well as productive lifetime can also have impacts on herd structure and productivity. A lower requirement for replacement livestock would result in more young livestock sold for consumption, though conversely, less adult livestock will enter the production chain as cull animals. As a key input, the feeding level and type of feeds required to achieve this level of performance were then specified according to the scenario and estimated nutritional needs. Within the livestock system specification, linkages between systems were also specified, such as a dairy system supplying young calves for dairy beef production.

LIVESTOCK HOUSING TYPE/ACCESS TO PASTURE

Existing livestock housing systems can vary considerably and characterisation within the future scenarios is likely to further exaggerate this as systems further differentiate. The intensive indoor systems are likely to include more technical development, with livestock housed continuously. More extensive scenarios are likely to include a greater use of outdoor access as well as improved space allowances and building design to enable more natural behaviour. Livestock housing type and manure systems can affect both animal welfare and emissions, therefore livestock housing type, including access to pasture were next to be specified. This data included the type of housing, space requirement and use of bedding/slatted floors. A key feature of some future systems would be improved access to the outdoors, as well as pasture stocking density and grazing style such as typical rotational or set-stocked grazing or could include alternatives such as mob grazing.

MANURE MANAGEMENT

With changes in building design or access to outdoors, manure quantities and type may alter under different future scenarios. Housing design may vary from fully enclosed with automated manure removal, through to open sided systems with deep bedding and enrichment materials. The type and length of manure management may vary between liquid to solid and storage systems may evolve, such as biodigesters, therefore systems and storage time were adapted as necessary to align with the storylines.

SYNTHESIS OF FUTURE SYSTEMS AND THEIR USE

Building on the initial baseline livestock systems developed in the Milestone 11 report and final baseline systems presented in this report, future livestock systems were developed that align with the storylines developed in Work Package 2. Through the development of future livestock system specifications, subsequent tasks can assess their relative performance and potential trade-offs using environmental and social LCA, as well as economic analysis. Development work was undertaken sector by sector to ensure integration and linkages with existing systems.

Results

The baseline and future system characterisation were undertaken for nine livestock categories: dairy cows, beef cows, finishing cattle, sheep (meat), sheep (dairy), goats (dairy and meat integrated), pigs (breeding and finishing), laying hens and broilers. The general results are discussed briefly, before subsequently presenting the systems for each livestock sector. Each class of livestock has a summary figure showing the various database derived clusters, the merge of clusters, the tree of systems derived from the surveys and the synthesis map, followed by a table of variables per system identified. Each table has a combination of data derived from both the database clustering and the surveys, to provide a wide as possible initial characterisation.

Baseline system characterisation

The Eurostat data derived analysis and HCPC allowed the creation of clusters for multiple livestock classes. For all classes it was possible to differentiate between livestock types, as Eurostat is based on the Farm Structure Survey FSS data. The FADN data analysis provided a wider range of farm system data, but the public database is limited to certain farm types at a NUTS2 scale, therefore it was difficult to differentiate between some livestock types, e.g. poultry. However, for some classes it was possible to overlay Eurostat data on FADN data layers at the NUTS2 level, e.g. dairy or meat sheep, therefore more customised clusters could be identified. The characterisation at livestock enterprise level based on experts and literature involved data collection from 9 countries comprising a total of 171 livestock systems: 24 dairy cow systems, 22 beef cow systems, 20 beef fattening systems, 9 dairy sheep systems, 14 meat sheep systems, 12 goat systems, 20 pig rearing systems, 21 pig fattening systems, 22 laying hen systems and 18 broiler chicken systems (Figure 3).

The synthesis of systems using the combination of the different levels of characterisation was based on the clustering with Eurostat and FADN data a merge of clusters was generated for each livestock category (except for poultry). This information was then contrasted with the survey defined systems and each unique cluster was aligned with system descriptors from the expert survey data. Each livestock class is described in the following section.

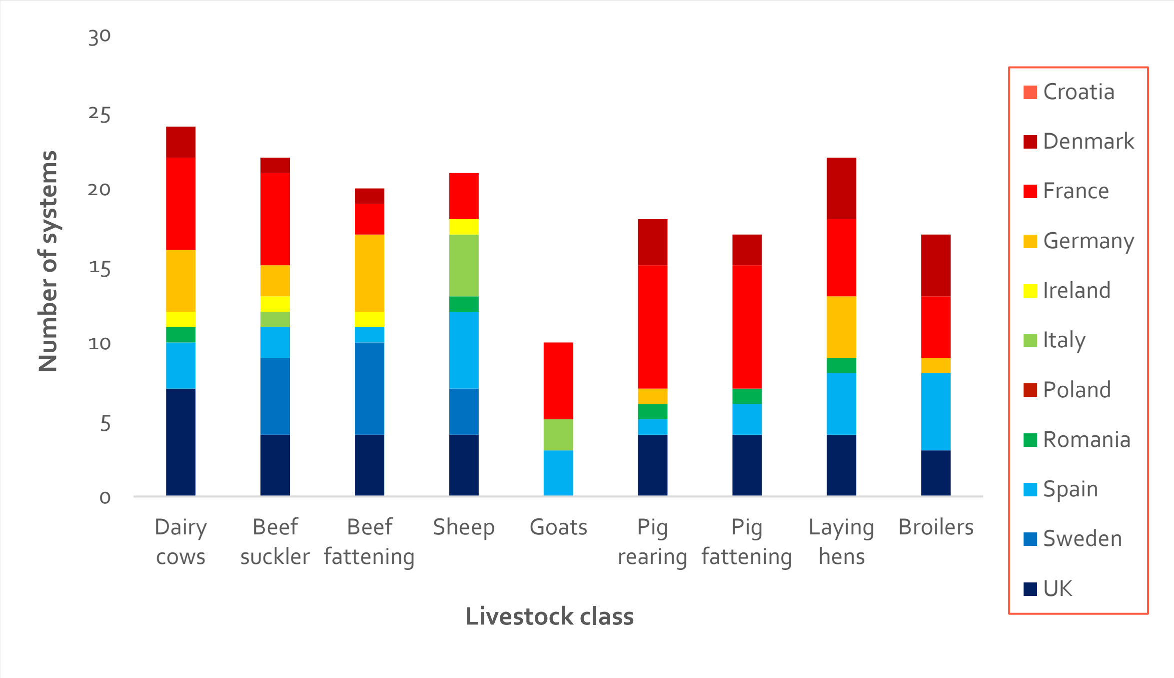

Figure 3 Systems collected through the survey per livestock category and country

Future system characterisation

The future systems were developed as scenarios for each sector based on the three selected storyline specifications (The Stockless storyline removes all livestock production and was therefore not compatible with redesigned livestock systems, whilst the Rural Renaissance storyline is based on socio-economic ideas related to regional self-sufficiency, so has less relevance for farm scale adaptations).
For each selected system scenario an appropriate baseline system was chosen and changes implemented to reflect the storyline requirements. Some of the scenario systems were omitted as they were viewed as incompatible, e.g. broilers were not compatible with FnF. However, in general, the future systems were developed to reflect both the desired outcomes of the storylines and differing pedo-climatic zones including northern vs southern or lowland vs upland attributes that for example, may impact the type of forages grown.

Dairy cows

BASELINE SYSTEMS

The detailed steps to identify the main dairy cow systems are shown in Dairy cow system baseline construction in the appendixAppendix 1 – Baseline systems. The process identified 6 main dairy system clusters, but due to the high availability of variables relevant to dairy cow production it was possible to also identify a number of sub-systems within these main types, as shown in Figure 4 and with key variable descriptions in Table 5.

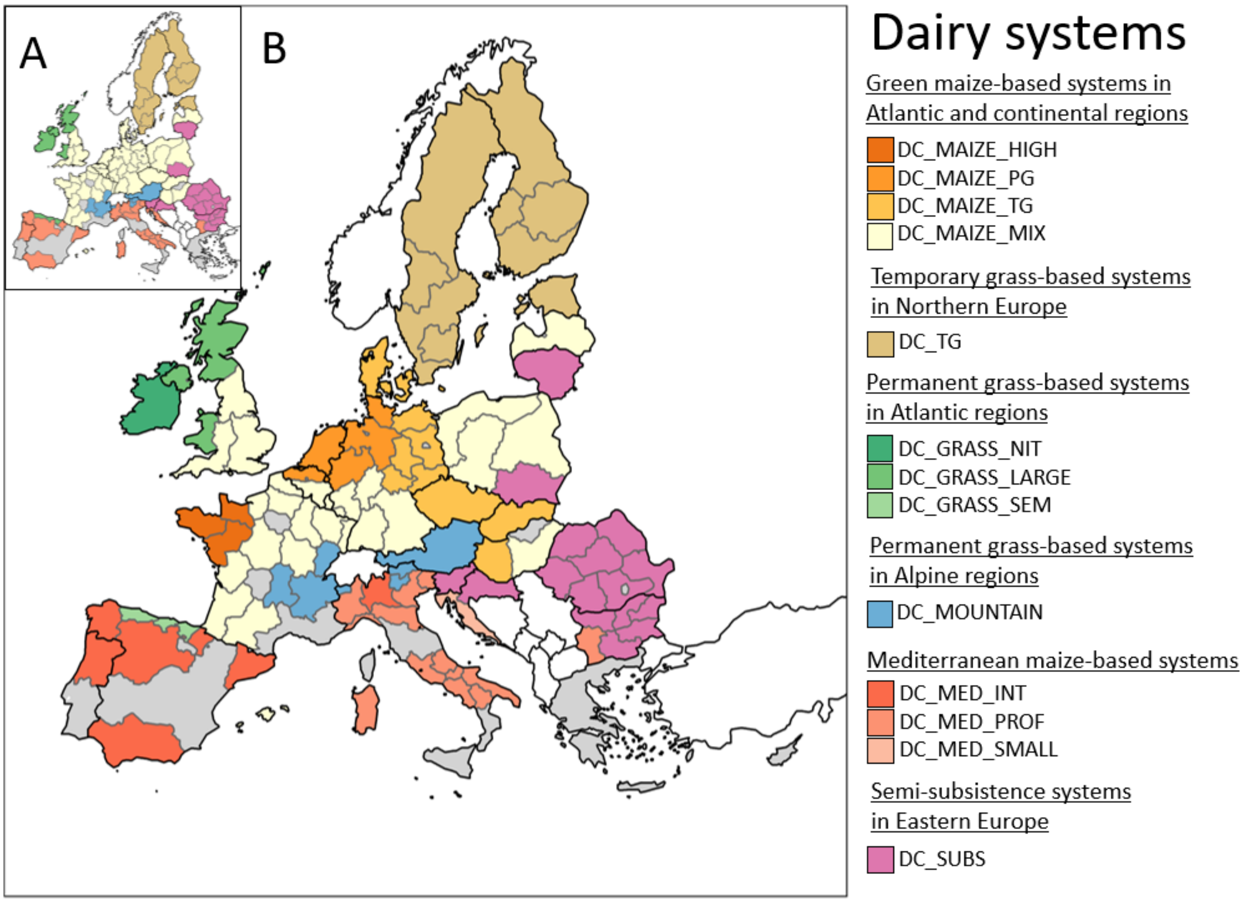

Figure 4 Baseline dairy cow systems

A: Map representing the general systems. B: Map representing the systems. The colours of Map B are explained in the legend. The underlined titles are the names of the main systems; the colours refer to the systems. See Table 5 for a short description of the systems.

Table 5 Description of the dairy systems based on expert interviews (and FADN data when stated).

System	Herd size (LSU)	Breed type	Milk yield (kg cow^{-1})	Roughage		Concentrates (kg cow year^{-1})
				Summer	Winter	
DC_MAIZE_HIGH	75 (FADN: 74 ± 4)	High yielding breed	8000 (FADN: 7038 ± 400)	Grazed grass, maize silage (5 months)	Maize silage, grass silage (7 months)	1100
DC_MAIZE_PG	100 (FADN: 99 ± 15)	High yielding breed	8700 (FADN: 8679 ± 213)	Grazed grass, grass silage (6 months)	Grass silage, maize silage (6 months)	1800
DC_MAIZE_LARGE	225 (FADN: 237 ± 96)	High yielding breed	10000 (FADN: 8654 ± 859)	Grass silage (7 months)	Grass silage, maize silage (5 months)	NA
DC_MAIZE_MIX	100 (FADN: 72 ± 40)	High yielding breed	8500 (FADN: 7304 ± 700)	Grazed grass (7 months)	Grass silage, maize silage (5 months)	1500
DC_TG	NA (FADN: 64 ± 27)	NA	NA (FADN: 9147 ± 468)	NA	NA	NA
DC_GRASS_NIT	90 (FADN: 79)	Smaller dairy breed	5600 (FADN: 5964)	Grazed grass (9 months)	Grass silage (3 months)	1000
DC_GRASS_LARGE	400 (FADN: 145± 37)	Local breed	6000 (FADN: 7668 ± 318)	Grazed grass (10 months)	Grass silage (2 months)	700
DC_GRASS_SEM	60 (FADN: 62 ± 10)	High yielding breed	3000 (FADN: 7671 ± 1610)	Grazed grass, hay (6 months)	Grass silage, grazed grass (6 months)	900
DC_MOUNTAIN	50 (FADN: 35 ± 17)	Dual purposed	6000 (FADN: 5868 ± 1549)	Grazed grass (4 months)	Grass hay (8 months)	1100
DC_MED_INT	200 (FADN: 87 ± 36)	High yielding breed	12000 (FADN: 8763 ± 1027)	Maize silage, grass silage		3300
DC_MED_PROF	NA (FADN: 43 ± 19)	NA	NA (FADN: 5730 ± 1296)	NA		NA
DC_MED_SMALL	5 (FADN: 8)	Dual purposed	7000 (FADN: 3460)	Maize silage, grass silage		1800
DC_SUBS	3 (FADN: 14 ± 10)	Local breed	5000 (FADN: 4341 ± 1081)	Grazed grass, hay (8 months)	Grass hay, alfalfa hay (4 months)	50

Intensive systems based on green maize and/or temporary grasslands

These systems seem to be the most common systems in the European Union. In these systems, cows are grazing for a part of the year on temporary and/or permanent grasslands and are partly fed with maize silage which can be combined with grass silage.

Intensive systems based mainly on green (silage) maize

In Western France and Northern Germany, dairy farms are medium to large (~100 ha), with herd sizes around 75 cows in France and 110 in Germany. These regions have a high share of green maize (10–25%) in land use and high milk yields, especially in Germany (8500 kg/cow/year). French regions like Brittany and Pays de la Loire have low permanent grassland (15%) but high temporary grassland (20%), aligning with conventional systems using maize and grass silage, and 1 tonne of concentrates per cow annually, though grazing may still occur in the spring/summer. Organic systems in these areas have lower milk yields (5500 kg/cow/year), reduced concentrate use, and longer grazing (9 months vs. 5). In Northern Germany, grazing is common, but large farms (≈200 cows) often use indoor systems.

Intensive system based on permanent grasslands and green maize

The Netherlands and northern Belgium have high proportions of permanent grassland (~60%) and green maize (~10%), with dense livestock populations and high milk yields. The dominant system is a "high input–high output" conventional model, with family farms averaging 100 cows and 60 ha. These farms use significant amounts of fertilisers and concentrates (1.8 t/cow/year), with cows fed maize and grass silage and grazing in summer (85% of farms). Despite high productivity, the system's sustainability is low due to nitrogen emission concerns from the Dutch government. Organic farming is minimal (<5%) and more environmentally sustainable, relying solely on grass feed, but faces economic challenges due to insufficient price premiums.

Large intensive systems based on green maize and temporary grasslands

Denmark, Eastern Germany, Czech Republic, Slovakia, and Hungary have low levels of permanent grasslands (10–20%) and moderate levels of temporary grasslands (5–10%) and green maize (5–15%). These regions feature high milk yields and large farms, mostly using hired labour. Farm sizes vary, with 100–200 cows and 100–300 ha in Denmark, Hungary, and the Czech Republic, and up to 350 cows and 950 ha in Slovakia and parts of Germany. The Danish conventional system is intensive, with mostly indoor housing (only 25% of cows graze, mainly in small herds), and feeding based on maize and grass silage. The organic system is also intensive but includes summer grazing alongside similar feed.

Systems based on temporary grasslands

In Sweden, Finland, Estonia and Latvia, land use is characterised by the highest percentages of temporary grasslands (around 30%). In Scandinavian regions, milk yields are particularly high (more than 9000 kg/cow/year), the farms are medium with 40-90 cows and 60-150 ha, and a high proportion of concentrate production on the farm (around 50%). These farms are also characterised by low profitability and high livestock subsidies. In Latvia, the farms were smaller with more permanent grasslands.

Intermediary systems based on both types of grasslands and green maize

Lowland regions in France, Germany, the UK, and Poland have intermediate levels of permanent and temporary grasslands and green maize. Farms are mainly medium-sized family farms (around 70 cows and 100 ha), though the UK has larger farms (170 cows, 150 ha with hired labour), and Poland has smaller family farms (20 cows, 30 ha). In France, regions like Normandy follow a crop-livestock system relying on pasture and on-farm forage, with diverse crops, high milk yields, 9-month grazing, and 1 t/cow/year of concentrates. This system is economically resilient due to its diversity, though milk production may be reduced to prioritise crops. In Poland, small traditional farms use tied housing, with cows grazing in summer and fed with hay and maize silage in winter.

Intensive grassland systems

Intensive grasslands systems were defined as systems based on permanent grasslands combined with an intensive land or livestock management (high nitrogen input, high livestock densities, large herds, important use of green maize).

High nitrogen input systems

According to European databases, farms in Ireland were of medium-large size and the dominant dairy systems are characterised by intense nitrogen values on pasture which can be an environmental issue ("low biodiversity in fields due to intense nitrogen use from slurry and mineral fertilizers"). Most of the time, the cows are partly grazing in summer on permanent grassland, but the system can also be completely indoor like in Northern Ireland. The feed is mainly based on grass silage with maize silage sometimes. The quantity of concentrates is medium to high (1 t/cow/year in Republic of Ireland and 2 t/cow/year in Northern Ireland).

Systems with large herds and large areas of land

In Great Britain, dairy systems typically involve large farms (150–200 ha) with herds of 100–300 cows. Two main systems exist, including a grazing-based system with long grazing periods (10 months), low concentrate use (<1 t/cow/year), and winter feeding with hay and grass silage. Or, a more dominant intensive system using high-yielding breeds, shorter grazing (5–7 months), high concentrate use (2 t/cow/year), maize silage in winter, and higher milk yields. This system may negatively impact the environment due to grazing intensity. In northern Spain, medium-sized farms (40–70 cows, 20–40 ha) are less intensive systems, including a semi-intensive organic grazing model. Cows graze in summer (on-farm and common lands), are housed in traditional tied stalls, and are fed grass silage in winter with low concentrate use (900 kg/cow/year). This system supports environmental and social sustainability, but economic sustainability is limited and depends on direct marketing for profitability.

Mountainous dairy systems

In the mountainous regions, permanent grasslands dominate (64–99%), livestock density is low (<1 LSU/ha), and milk yields are moderate (~6000 kg/cow/year). French Alpine farms are larger (50 cows, 100 ha), while Austrian and northern Italian farms are smaller (20 cows, 20–60 ha) and mostly family-run. Two mountain dairy systems were described including the Massif Central system which uses smaller dairy breeds (e.g. Salers), with 4-month grazing, feeding on permanent and temporary grasslands, though some systems also use larger Montbéliard cows. In winter, cows are fed grass silage and or hay and 1400 kg/cow/year of concentrates. Milk is sold as liquid, but the system has low economic and social sustainability due to poor milk prices and limited forage potential. Secondly, the Jura system as described is based on permanent grasslands (90%) and dual-purpose breeds (e.g. Montbéliard), with cows grazing for four months and fed only hay in winter with 1000 kg/cow/year of concentrates. Milk is used for AOP Comté cheese, ensuring high economic and social sustainability through stable prices and better working conditions. The environmental sustainability is high, though risks exist from increasing production intensity (e.g., rising livestock densities).

Mediterranean systems

According to the European databases, Mediterranean regions were similar because of high dairy cow densities. This can be linked to the indoor systems described in the survey for Spain and Croatia. These regions showed particularities, as outlined below.

Intensive indoor systems with high milk yields

In most of Spain and central Portugal, dairy farms are large (around 100 ha and 100 cows), with high milk yields and little reliance on home-grown feed. Labour is mostly hired. These farms follow intensive dairy systems, with sizes ranging from 80 to over 500 cows. Medium farms (around 50 ha) are often family-run with 1–3 employees, while the largest farms may have little or no land, and rely entirely on hired labour and proximity to process facilities. Grazing is not used for lactating cows; in smaller farms, only heifers and dry cows may access pasture. The systems are economically viable, though all face labour shortages. Milk production is high and based on very high concentrate use (>3 t/cow/year or >0.4kg/litre), with diets mainly composed of purchased maize silage, grass silage, hay, and concentrates. The largest farms also buy most of their fodder.

High profitability systems

In some Italian regions and the Eastern region of Bulgaria, the regions were characterised by systems with a higher profitability, and a low milk yield. These farms were generally rather small (around 30 ha) but with medium-sized herds (60 cows). In Italy, the profitability was driven by high-value products, e.g. Reggio-

Emilia (IT) was characterised by a particularly high level of temporary grasslands and leguminous crops linked to alfalfa for Parmigiano cheese.

Small intensive indoor systems

In Croatia, dairy farms are generally small (about 10 cows, 20 ha), with low milk yields (~4000 kg/cow/year) and a high share of home-grown concentrates (85%). There is regional diversity in systems with continental Croatia (e.g. Slavonia) being more specialized and intensive, with low permanent grassland (20%) and some use of temporary grasslands and green maize. Whilst the coastal region is more extensive, with very high permanent grassland use (83–92%). Dairy production is mainly intensive and indoor, using dual-purpose breeds like Simmental. Cows are largely kept indoors, with limited outdoor access due to heat stress in summer. The sector is split between family farms and large corporations, but economic and social sustainability is weak due to volatile milk prices and an ageing farmer population, raising concerns about the future of small farms.

Semi-subsistence dairy systems

In Eastern EU regions (Romania, SE Poland, Lithuania, Slovenia, Bulgaria), dairy farms are very small (≈10 ha, 7 cows), with low to medium milk yields (~4000 kg/cow/year) and a high but variable share of permanent grasslands. Farms rely heavily on home-grown feed (≈50%) and family labour, facing financial challenges. These are typically semi-subsistence mixed farms, where dairy is the main income source, and other livestock (pigs, poultry, sheep) are raised for household use. The farming structure varies by geography—more pigs in lowlands, more cows in mountains. Land use is diverse, with permanent grasslands often featuring agroforestry elements, and mixed crops for family use. Cows are grazed seasonally, with communal grazing common in Romania (May–November). In winter, cows are housed traditionally and fed grass and alfalfa hay. Breeds include dual-purpose or rustic types (e.g., Simmental, Bălțată Românească).

FUTURE SYSTEMS

The future dairy systems were developed and described in the following sections. In total, six systems were developed as relevant examples, to represent the three storylines and differing pedo-climatic zones.

Efficiency First

The EF dairy sector was re-designed as two systems, differentiated into northern and southern pedo-climatic conditions. In the north and west regions of Europe an EF system was developed based on the already intensive Danish model, with increased milk yields based on grass and maize silage, combined with a high level of concentrated feedstuffs. In the south, the intensive Italian Grana Padano system was utilised as the base system, using a variety of feeds including maize and grass silages as well as lucerne and intensive use of concentrate feeds. Both systems embrace larger herds of cows, housed all year round in ventilated sheds and fed a combination of methane inhibiting feed additives including 3NOP and nitrate and with breeding selection for reduced methane (Aan Den Toorn et al., 2021) to reduce emissions by up to 50%. The use of technologies for precision feeding and feed intake monitoring (e.g. biometric sensors for recording feeding behaviours) result in improved feed use efficiency (Centre for Innovation Excellence in Livestock (CIEL), 2022). This, combined with increased milking frequency using robot milking systems, improved animal health through enhanced disease monitoring and improved breeding values for yield, result in milk yield of 12,500 kg/cow/yr (150 and 120% increase in Danish and Italian examples, respectively – the yield increases in the latter being lower due to already high yields). Improvements in young stock feeding and health management result in improved calf growth rates, enabling heifers to be calved 22 months at a body weight of 620kg (Bach et al., 2021). Breeding technologies such as genomic tools and sexed semen are used to increase the rate of genetic improvement with traits such as productivity relative to cow size, feed efficiency, fertility, longevity and health being of key importance (Centre for Innovation Excellence in Livestock (CIEL), 2022). Replacement rates of 30% (average 3.33 lactations) are achievable despite significant yield increases using technologies to better support animal health and disease monitoring, as well as previously mentioned breeding and nutrition practices. Slatted floors or scraped passageways pass slurry into on-farm anaerobic biogas digesters (Aan Den Toorn et al., 2021), generating energy and providing digestate as a fertiliser. This CH_4 collection as well as the use of CH_4 inhibitors in the slurry reduces emission by 50% (Centre for Innovation Excellence in Livestock (CIEL), 2022). Forage productivity is maximised through the combined use of manures, supplemented with mineral fertilisers. The use of nitrification inhibitors reduces N_20 emissions from fertiliser by 29% (Akiyama et al., 2010).

Feed no Food

The FnF system was also re-designed as two systems, this time represented by lowland temperate and continental mountainous pedo-climatic zones. FnF is unsuitable for southern Europe due to high temperatures limiting grass growth and grazing potential in summer, and land used to grow forage crops now being used for food crops. In the north west of Europe the FnF system was based on the Irish example of intensive grass growth for both grazing and silage production (supported by high levels of nitrogen fertilisers) with Holstein Friesian cows being the predominant breed (McClearn et al., 2020). The second FnF system is based on the mountainous systems in Jura, (France and Switzerland) which utilises grazing and hay from permanent grasslands (90%) and dual-purpose breeds (e.g. Montbéliard). Both current systems can limit grazing (4-6 months) and rely on 1000kg of concentrate/cow/year to achieve moderate milk yields of 6000-6500 kg/cow/yr). This extra feed will be removed under the FnF scenario resulting in reduced milk yield at 85% of current levels (2025) and reduced stocking rates (currently 2.75 cows/ha in Ireland) at pasture to ensure sufficient silage feed available for the winter housing period. The removal of concentrate in the mountain FnF system may result in milk composition changes – an important issue for example in the making of Comte cheese - some by products could be used to supplement the diets in both systems. The protein content and yield of both fresh and conserved grass in can be improved with the greater use of multispecies swards (Lüscher et al., 2014) – also allowing a reduction in N fertiliser levels (90% of current) (Baker et al., 2023). The use of smaller breeds e.g. Jersey x Holstein Friesian or x Norwegian Red, will reduce maintenance feed inputs without significantly compromising total milk yield (McClearn et al., 2020). Replacement rates are predicted to remain the same (~27%), however with the loss of calf starter concentrate rations, age at first calving may be increased slightly to 28 months for both systems. Mortality rates for cows and replacement animals remain the same at 2% and 5%, respectively. Feed and manure/slurry additives can be used during the limited housing period (25% of the year in Ireland, 50% in mountains) to reduce enteric CH_4 by 22%, (Lahart et al., 2025), manure CH_4 and N_20 (-30%) emissions, respectively . During the grazing season, twice daily CH_4 inhibitor intake within a vitamin and mineral pellet at milking allows for a 10% reduction in enteric CH_4 (Muñoz et al., 2024).

High Animal Welfare

The high animal welfare (HAW) scenario is based on the same two systems as FnF, primarily because they are both based on pasture (grazed and conserved) diets, which allow species specific foraging, though small quantities of concentrate feeding and beneficial compounds would be allowed. The lowland temperate system as observed in Ireland is currently based on pure ryegrass swards, the yield of which is supported with relatively high N fertiliser inputs. Under the HAW scenario this will require a shift to more diverse swards, including legumes, which would more naturally reflect a ruminant diet, but which also reduces the amount of N fertiliser inputs required. Multispecies swards have also been shown to produce greater DM than pure ryegrass, with less than half the N fertiliser (Shackleton et al, 2024). Grazing and conserved forage (hay) in the current mountainous systems in the mountains tends to be on naturally diverse permanent pastures therefore major shifts in current pasture composition are unlikely to be required or (desired from a biodiversity perspective) to accommodate the HAW scenario. Implementing mob grazing strategies in both systems will provide both potential health (prolonged rest between grazing will reduce intestinal parasite burdens) and welfare benefits such as enabling stable family groups to be grazed together (Wagner, Waterton and Norton, 2023). Mob grazing can however result in reduced pasture quality/changed pasture composition compared to rotational grazing (Billman et al., 2020) and therefore small reductions (5-10%) in stocking rate will be required to account for this. Smaller, dual-purpose breeds are likely to be better suited to this system both due the reliance on pasture grazing and to achieve a better balance between productivity and longevity traits (Bieber et al., 2019). To maximise cow-calf welfare, calves will be kept at foot and allowed to feed ad libitum from their mothers for a minimum of 90 days, after which they will be weaned and calves not needed as replacements, sold. During this 90 days rearing period, approximately 50% of the milk produced will be consumed by the calves and subsequent milk yield during the remainder of the lactation will be reduced – resulting in a 25% reduction in total milk sold (Barth, 2020). Suckling at this intensity has been shown to significantly reduce milk fat content during the suckling period, however, conversely, milk protein % is increased (Barth, 2020). Due to a preference for natural animal functioning, feed additives to reduce methane would not be fed within HAW, and methane emissions would be assumed to be as estimated using IPCC Tier 2 estimations. Housing would allow more space for animals and be based on deep straw bedding for maximum comfort, strongly affecting the type and quantities of manures produced.

Suckler (Beef) cow systems

The steps to identify the main suckler cow systems are shown in Appendix 1: Suckler cow system baseline construction, which identified 6 main suckler cow system clusters, as shown in Figure 5, and with key variables in Table 6.

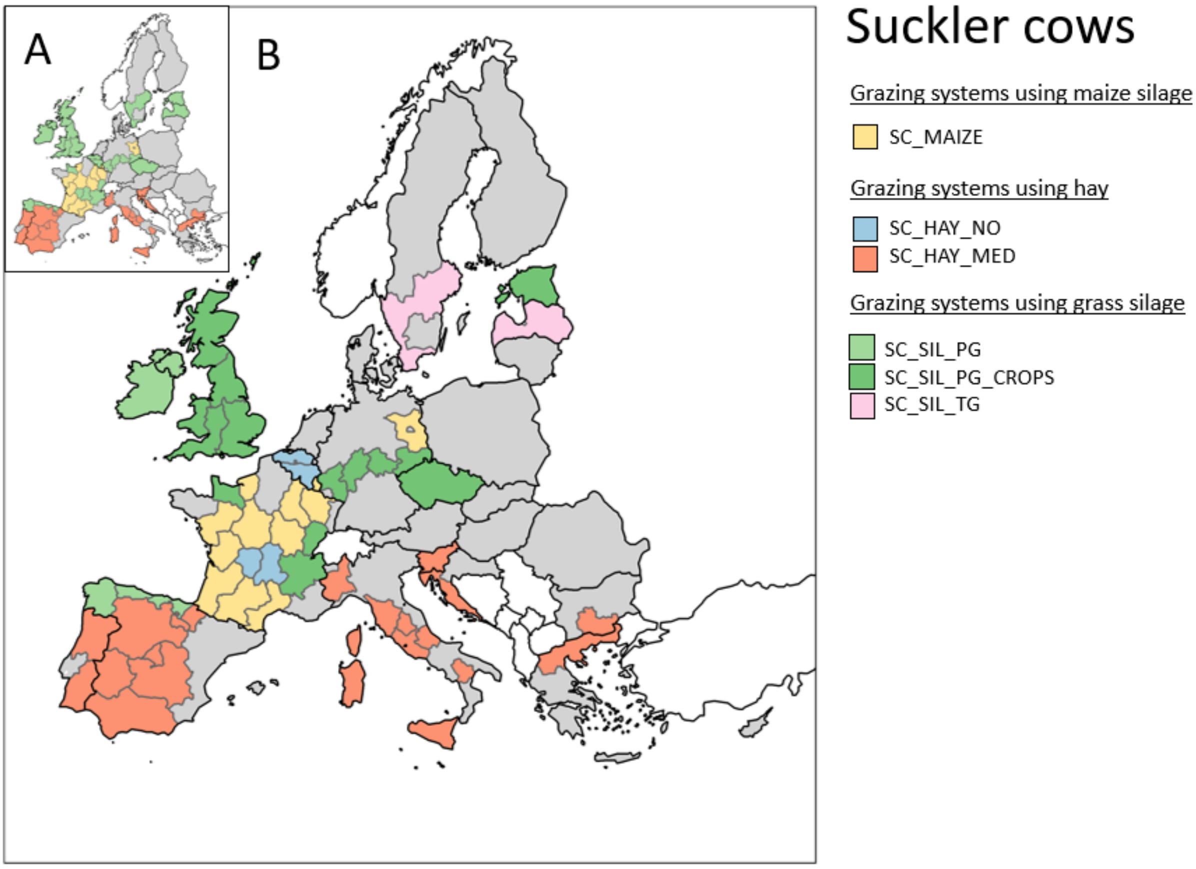

Figure 5 Suckler cow systems

A: Map representing the general systems. B: Map representing the systems. The colours of Map B are explained in the legend. The underlined titles are the names of the general systems; the colours refer to the systems.

Table 6 Description of the suckler cow sub-systems

System	Herd size (LSU)	Main breed type	Roughage		Concentrates (kg bovine year^{-1})	Permanent grasslands (% UAA)
			Summer	Winter		
SC_MAIZE	120 (FADN: 124 ± 29)	Typical beef	Grazed grass (6 months)	Maize silage, grass hay (6 months)	670	5 (FADN: 64 ± 11)
SC_HAY_NO	190 (FADN: 107 ± 10)	Native	Grazed grass (5 months)	Grass hay, alfalfa hay (7 months)	350	100 (FADN: 62 ± 12)
SC_HAY_MED	50 (FADN: 51 ± 37	Typical beef and native	Grazed grass (7 months)	Grass hay, straw or alfalfa hay (5 months)	200	60 (FADN: 72 ± 23)
SC_SIL_PG	30 (FADN: 45 ± 8)	Typical beef	Grazed grass (10 months)	Grass silage (2 months)	100	90 (FADN: 93 ± 7)
SC_SIL_PG_CROPS	30 (FADN: 91 ± 35)	Typical beef	Grazed grass (9 months)	Grass silage (3 months)	250	90 (FADN: 79 ± 6)
SC_SIL_TG	30 (FADN: 46 ± 17)	Crossbred and typical beef	Grazed grass (6 months)	Grass silage, straw (6 months)	0	50 (FADN: 40 ± 16)

BASELINE SYSTEMS

Permanent grass extensive systems

The humid Atlantic regions of Ireland, UK and Northern Spain are typical of the extensive permanent grassland suckler cow systems. These types of farms were largest in the UK and use native or typical beef cow breeds, with good livestock longevity and medium sized herds. Grazed grass and grass silage form the basis of the diet, with relatively low levels of concentrate.

Intensive temporary grass systems

These lowland beef herd systems are predominately based in France. The farms have a large UAA and high herd sizes of 120-180 livestock. These systems often rear and finish the livestock, using typical breeds fed on a mixture of grass (temporary and permanent) and maize, as well as food byproducts, including root vegetable waste. Grazing is less than on permanent grass systems, and concentrate feeding is higher.

Mediterranean extensive systems

The predominant beef cow system in the Mediterranean extends from Western Portugal across to some regions of Greece. The farms are typically smaller than the French or Atlantic systems, with herd sizes of 50-70 livestock. The diet can be quite varied across regions, including grass as grazing or hay, but also straw as available, combined with a higher level of concentrates.

Mountain extensive French system

Within the upland and mountainous regions of France and Belgium, typified by the Massif Central, grassland farms host large suckler beef herds. These grazing and grass hay systems typically rear calves for sale, that are often finished in Italy or Spain.

Swedish system

The Swedish was identified due to its greater reliance on temporary grasslands, smaller herd size and lower grazing days due to the northern climate. The concentrate feeding level is relatively low, with grass silage forming the basis of winter feeds.

FUTURE SYSTEMS

The future beef cow systems were developed and described in the following sections.

Efficiency First

The beef cow systems defined as baseline systems would be vastly reduced with an EF scenario. Unfortunately, as the beef cow systems result in some of the highest environmental impact foods available, and with few options for mitigation, this sector would be reduced to extensive upland grazing for conservation purposes only and is therefore not assessed within the EF storyline.

Feed no Food

Within the FnF storyline the more extensive suckler beef systems that rely on converting fibrous, lower quality pastures into high quality food are utilised as baseline systems (SC_HAY_MED and SC_SIL_PG). The suckler cow systems continue to utilise the land less suited to dairy production, though their numbers would likely reduce due to an expansion of dairy utilisation of permanent grassland and elimination of concentrate feeds. Stocking rates would be determined by a balance between providing enough forage for grazing animals, maintaining pasture quality and conserving sufficiency forage for the housed winter period. This is the same as many existing extensive pasture based suckler systems, however, most would currently feed some calf creep feed to calves to reduce checks to growth around weaning (Viñoles et al., 2013). As concentrate feeding is avoided in the FnF storyline, stocking rates may need to be reduced slightly (5%) to ensure sufficient, high-quality feed for these animals. The genotypes adapted to extensive suckler systems include good maternal abilities, their relatively high intake capacity (for their mature body size) of roughages and low-quality grass, and their ability to mobilize then recover body reserves (d'Hour et al., 1998). Where specialist beef breeds are used (e.g. Hereford or Angus) introducing dairy genetics through cross breeding can increase calf growth rates through improved milk yields, but may impact negatively on final carcass growth and composition (Sapkota et al., 2020). However, crossbreeding of common beef breeds including Limousin and Charolais may help produce lower fat carcasses. Calf daily liveweight gain in systems where calf growth rate is supported with concentrate feeds typically exceed 1kg/day from birth to weaning (AHDB, n.d.), without these inputs, calf growth rates will be reduced by 25-30% (Viñoles et al., 2013). Reproductive performance parameters (replacement rate, age at first calving, number of lactations, calving interval) are unlikely to differ from current extensive systems. Typically, cattle would be housed for the winter (3 months) during which time methane inhibitors could be fed with silage/hay to reduce CH_4 emissions with assumed 22% effectiveness due to the high forage content (Lahart et al., 2025), however during the summer grazing months no inhibitors would be fed.

High Animal Welfare

The HAW storyline is based on the same extensive, pasture based suckler systems used in the FnF storyline (SC_HAY_MED and SC_SIL_PG). These are relatively “natural” systems in that they rely predominantly on grazed grass, with conserved silage or hay feed over the 3 months of winter house. Traditional native genotypes (often dual-purpose) are commonly used currently due to their good maternal ability, ability to thrive on relatively low-quality forage, and general hardiness (d’Hour et al., 1998) and these are equally appropriate under the HAW storyline. Weaning would take place naturally at around 9 months of age (as it does currently) and weaned calves could either be sold as stores or grown and finished on pasture over a period of 30-36 months. Unlike the FnF storyline, some purchased feed could be used to support calves through the weaning transition. As with the dairy system under the HAW story line, implementing mob grazing strategies will provide both potential health and welfare benefits such as enabling stable family groups to be grazed together (Wagner et al., 2023). The low stocking rates currently seen in these extensive systems mean that they are unlikely to need to be reduced further under the HAW storyline. Cows could be housed for 3 months over winter in loose housing with plenty of straw, or more hardy native breeds could be wintered outdoors and fed extensively, such as via bale feeding on pasture.

Finishing cattle systems

The steps to identify the main finishing cattle systems are shown in Finishing cattle system baseline construction in the appendix, and identified 3 main finishing cattle system clusters, as shown in Figure 6, with key variables highlighted in Table 7.

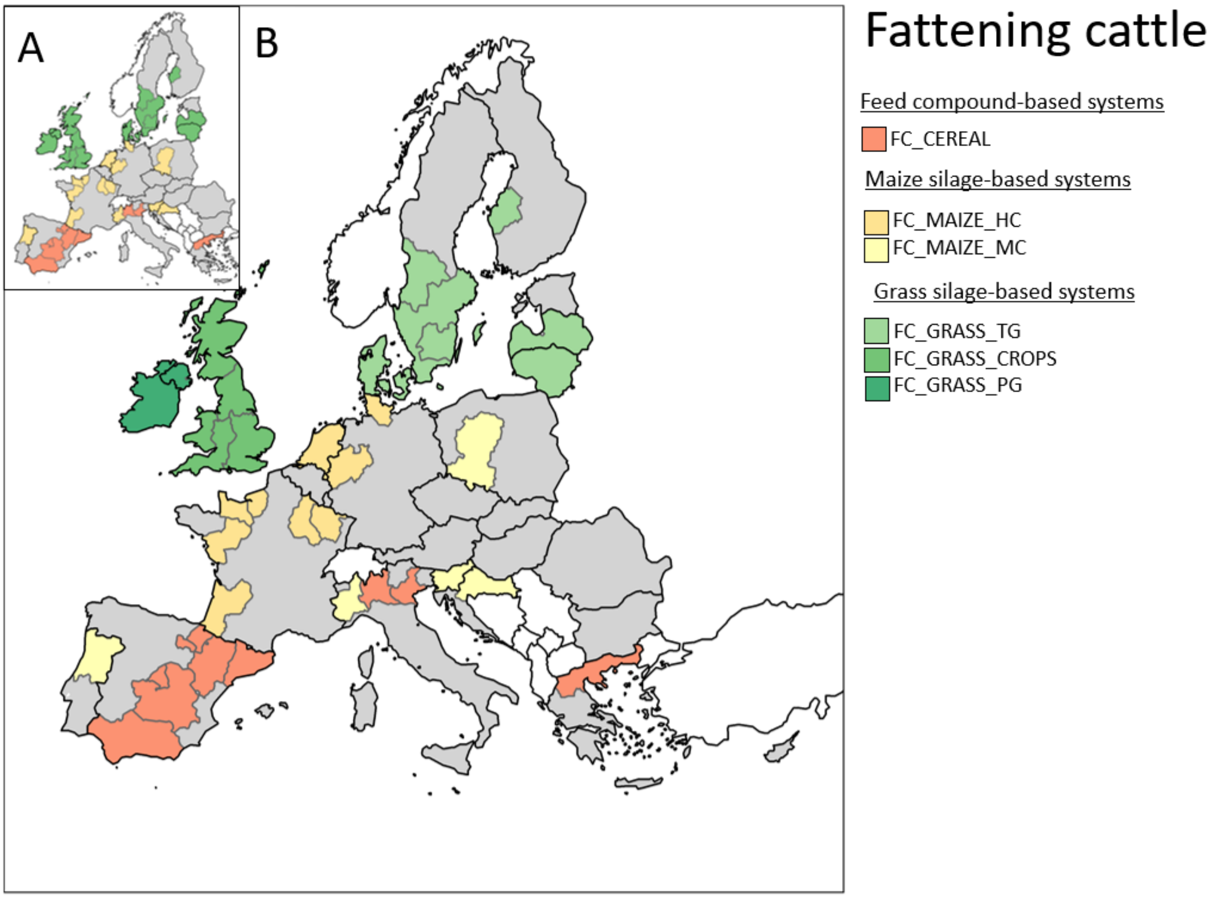

Figure 6 Fattening cattle systems

A: Map representing the general systems. B: Map representing the systems. The colours of Map B are explained in the legend. The underlined titles are the names of the general systems the colours refer to the systems.

Table 7 Description of the fattening cattle

System	Herd size (LSU)	Main breed type	Roughage		Concentrates (kg bovine year^{-1})	Home-grown concentrates
			Summer	Winter		
FC_CEREAL	450 (FADN: 96 ± 53)	Crossbred dairy/ typical beef	Feed compounds		1400	0 (FADN : 11.7 ± 10.2)
FC_MAIZE_HC	150 (FADN: 109 ± 30)	Typical beef	Maize silage		2200	0 (FADN : 15 ± 5.9)
FC_MAIZE_MC	NA (FADN: 27 ± 21)	Typical beef	Maize silage, Grass silage		500	50 (FADN : 62.5 ± 19.5)
FC_GRASS_TG	50 (FADN: 48 ± 19)	Crossbred dairy/ Typical beef	Grass silage		700	90 (FADN : 71.5 ± 14.1)
FC_GRASS_CROPS	120 (FADN: 109 ± 26)	Typical beef	Grazed grass (8 months)	Grass silage (4 months)	500	50 (FADN : 57.2 ± 11.1)
FC_GRASS_PG	70 (FADN: 50 ± 9)	Typical beef	Grazed grass (10 months)	Grass silage (2 months)	500	0 (FADN : 48.3 ± 5.4)

BASELINE SYSTEMS

Cereal fed cattle

Cattle finishing systems with a high level of cereal or compound feeding were dominant in southern Europe, and for example specifically located in lowland northern Italy in the Po valley. Larger fattening farms were also visible in Spain, as well as other regions including northern Germany. These systems seem to be linked to the dairy industry and may include young bull fattening at <12 months old or medium growing systems in Spain, with slaughter at 15-18 months.

Grass silage fed cattle

Cattle finishing with grass silage is the dominant system in north and north-western systems, such as in Ireland, UK and Scandinavia. The young cattle are either sourced from dairy or suckler herds and reared on grazing and or grass silage and concentrates. Usually slaughtered at around 15-18 months, some may be reared with less concentrate feeds and reach maturity at around 24 months. This system can include grazing or indoor feeding of silage.

Intensive maize silage fed cattle

Some cattle finishing systems utilise maize as the primary feed, and these are typically situated in France, extending up to Denmark or also further east to e.g. Croatia, and likely also Germany and Austria. The young cattle are likely sourced from dairy herds in Denmark and the Netherlands, whilst France and Croatia may also source suckler reared livestock. Finishing can occur at between 15-24 months depending on breed and intensity of feeding, but usually livestock will not graze.

FUTURE SYSTEMS

The future beef finishing systems were developed and described in the following sections.

Efficiency First

Two beef systems were defined, based on pedo-climatic regions, to include southern systems based on FC_CEREAL using irrigated maize and lucerne, together with concentrate feeds and byproducts and northern systems based on FC_MAIZE_HC, relying on intensively managed grassland to provide forage. The southern systems would be more reliant on maize or cereal silages and irrigated forages, with both systems supported by concentrate feeds to enable rapid growth rates. Within the EF scenario, the beef rearing and finishing sector relies almost entirely on the dairy sector for sourcing of young livestock. Dairy cows are crossed with sexed semen to produce beef X dairy males (late maturing animal), which can be reared intensively on high quality forage and concentrate feeds, through indoor or open yard systems. Finishing weights of 600-650kg and feed conversion ratio of 6-7kg DMI/LWG could be expected, with a finishing age of 12-14 months (Juniper et al., 2007). Confinement allows for the feeding of methane inhibitors to reduce emissions with a 67% efficiency achieved with 3-NOP and nitrate (Aan Den Toorn et al., 2021), as well as collection of manure for bio digesting reducing manure management emissions by up to 10% through frequent clearing and digesting of waste. Indoor housing systems would be climate controlled to reduce heat stress and maximise feed efficiency. The use of automated feeders, real-time intake monitoring and nutrient modelling would be used to minimise feed waste and maximise gains (+1.8kg LWG/day (Juniper et al., 2007). Technologies applied in dairy systems, such as rumen boluses, could be used to monitor rumen health and avoid conditions such as rumen acidosis and associated laminitis.

Feed no Food

Cattle finishing based on grass silage is commonly see in the northwest of Europe (e.g. Ireland, the UK and Scandinavia) and the future scenario based on FC_GRASS_PG. In southern Europe, intensive finishing is more common (e.g. FC_MAIZE_MC), and in a more limited on way in southern Europe on semi-natural grasslands that avoid the use of cropland. Typically, these systems would produce grass grazed suckler bred steers at 24 months of age, finishing indoors using grass silage moderate concentrate inputs (700 kg dry matter (DM)/head) (Drennan & McGee, 2009), however, under this storyline, the removal of the concentrate feed element for finishing would reduce the energy in the diets, reducing the rate of liveweight gain and fat deposition. This increases time to finishing e.g. at a finishing carcass weight of 390kg (late maturing beef breed), a system with some concentrate input (as described above) would finish in 24 months vs a grazed grass and grass silage only system which would take 28 months. There are unlikely to be differences in carcase composition between cattle fed concentrate during finishing and grass/grass silage only, however grass-fed beef has a more desirable fatty acid consumption compared to concentrate-fed beef (Siphambili et al., 2020) which may provide marketing advantages. The forage only finishing system would remain largely unchanged from those feeding concentrate, other than the longer finishing period would results in more manure produced for either soil fertility building or biogas production. Housed periods such as finishing indoors on grass silage would facilitate the use of methane inhibitors to reduce methane emissions, with a 22% reduction assumed (Lahart et al., 2025). Increased use of legumes in the forage mixes, especially for temporary forages could slightly offset the removal of concentrates through increased protein supply and digestibility.

High Animal Welfare

Finishing animals under this storyline would follow on from the HAW suckler beef storyline, utilising FC_GRASS_PG and FC_GRASS_TG as baseline systems. They would also have many similarities to the Feed no Food storyline in that they utilise forage-based feeding systems with perhaps a greater emphasis on grazed pasture (conserved forage only during winter housed periods, not to speed up the finishing process), and the use of forage adapted, early-maturing native, or dual-purpose breeds. Based on this, animals are unlikely to be finished before 30+ months of age (HCCMPW, 2014). Pasture management under this storyline is very similar to that of the HAW dairy storyline. Typically, heifers and steers are most suited to this type of extensive pasture-based finishing systems as bulls will finish very quickly at light weights. The castration of intact males to improve production potential may not be acceptable under this storyline, however, given the potential for aggression amongst sexually mature intact male beef cattle, and the risk of injury to themselves and other animals, the welfare benefits of castration may outweigh the welfare benefits of not castrating, and other options such as chemical castration may be viable. If left un-castrated, male and female animals would need to finish separately to avoid unwanted breeding. Cattle would be loose housed for 3 months over winter, the rest of the time they would be grazing.

Meat sheep (lamb) systems

The steps to identify the main meat sheep systems are shown in Meat sheep (lamb) system baseline construction in the appendix, and identified 6 main meat sheep system clusters as shown in Figure 7, described subsequently, with key variables sourced from all data sources highlighted in Table 8.

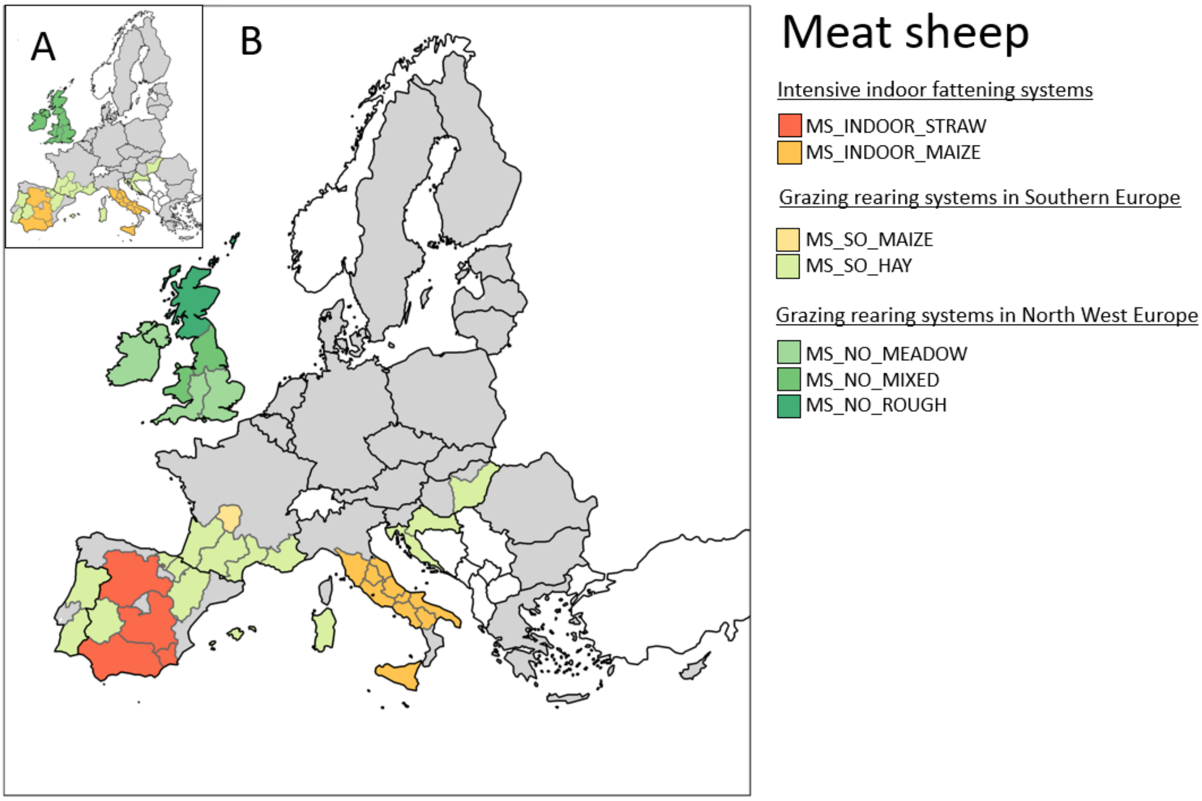

Figure 7 Meat sheep systems

A: Map representing the general systems. B: Map representing the systems. The colours of Map B are explained in the legend. The underlined titles are the names of the general systems; the colours refer to the systems.

Table 8 Description of the meat sheep systems

System	Herd size (ewes)	Main breed type	Main roughage		Concentrates (kg sheep year^{-1})	Grazing days
			Summer	Winter		
MS_INDOOR_STRAW	2500 (FADN: 730 ± 140)	Dairy	Straw		40	0
MS_INDOOR_MAIZE	140 (FADN: 220 ± 90)	Meat lowland	Maize silage		50	0
MS_SO_MAIZE	500 (FADN: 620)	Meat lowland	Grazed grass (5 months)	Maize silage & hay (7 months)	170	180
MS_SO_HAY	200 (FADN: 340 ± 220)	Meat mountain	Grazed grass	Hay	20	365
MS_NO_LOWLAND	300 (FADN: 550 ± 280)	Meat mountain	Grazed grass	Grass silage and hay	50	300
MS_NO_UPLAND	700 (FADN: 1080 ± 150)	Meat mountain	Grazed grass		25	365
MS_NO_HILL	850 (FADN: 1320)	Meat mountain	Grazed grass		25	365

BASELINE SYSTEMS

Intensive indoor (straw/maize) - meat sheep

These systems were mainly identified in Italy and comprises intensive maize silage or straw and concentrate feeding of lambs, though may also operate similarly in for example, France and Spain. The system operates in a similar method to indoor beef fattening.

Southern Europe (intensive maize silage) - meat sheep, FR

This system seems typical of France, with lowland systems based on maize silage and pasture. The system relies on concentrates for lambs and ewes, whilst ewes are specialist meat breeds.

Southern Europe Extensive grazing meat sheep

This system is common across southern Europe with medium to larger flocks and grazed permanent grassland the predominant feed. Concentrate feeds are fed at a medium level, to breeds which are mainly native to the region. Ewes might be housed at lambing or the peak of winter but mainly graze.

Northern lowland - meat sheep

This system is dominant in lowland UK and Ireland, characterised by large farms and flocks in the UK and smaller operations in Ireland. The systems are almost entirely grass based, with grazing for much of the year and grass silage or hay fed in winter, together with a medium level of concentrates. Most farms will rear all their own lambs for slaughter.

Northern upland - meat sheep

This system is the predominant specialist meat sheep production in western and northern UK – so called “upland” sheep production. As with lowland production, pastures are predominately permanent pasture, with ewes grazing for all the year except for lambing time. Concentrate feeding is low and productivity is less than the lowlands, however most lambs are finished on the same farm.

Northern hill grazing of large flocks - meat sheep

This system is dominant in Scotland and comprises very extensive grazing of mountains with specialist hill breeds adapted to the harsh production climate. Ewes will graze all year round but move to more favourable fields at lambing. Some lambs will be finished on the farm but may will be sold as “stores” and finished on lowland farms that have prepared winter brassica crops.

FUTURE SYSTEMS

The future meat sheep systems were developed and described in the following sections.

Efficiency First

Two system approaches were identified and reflect the differences in production between northern and southern European regions. The first is intensive lowland sheep breeding and finishing integrated into mixed arable cropping in mid to northern climates typical of France and the UK (MS_NO_LOWLAND). Productive ewes (e.g. Lleyn breed types with 200% lambing percentage) lamb indoors three times every two years on high quality leguminous silage and concentrate (1kg/ewe/day in late pregnancy/early lactation). Ewes lamb every 8 months using hormonal implants and are either kept indoors in yards or turned out with their lambs onto grass/clover leys (in a 4-year rotation), rotationally grazed to maximise utilisation, control quality and allow surpluses to be conserved as silage for feeding at housing. Lambs are weaned after 8 weeks and are creep fed with concentrates alongside high-quality forage to maximise growth rates (average LWG of 350g+/day) and finish at 40kg liveweight. Ewe lambs and dry ewes graze cereal stubble and or cover crops, as well as areas of uncultivated permanent pasture. Depending on feed availability, additional purchased store lambs could also be finished over winter on cover-crops (e.g. forage rye/clover) or stubble turnips/fodder beet (NSA, 2017). The use of break crops such as stubble turnips reduces intestinal parasites and the need for anthelmintics. Electric fencing and movable water troughs are used to maximise utilisation and regular monitoring of lamb growth rates/faecal egg counting ensures high lamb growth performance. Vaccinations, targeted nutrition at lambing/early lactation, closed breeding flock and strict hygiene measures in housing ensure good lamb survival rates (>95%) scanning to weaning and few health issues. Stock numbers are limited by the area of grass and forage crops in the rotation. Due to a mixture of grazing and housing, methane inhibitors would have little impact on an annual basis, potentially reducing enteric methane by ~15% (50% housed*29% reduction (Martínez-Fernández et al., 2014) when fed).

The second lamb system under the EF storyline is the intensive maize silage feeding of lambs indoors, as seen in Italy, France and Spain (MS_INDOOR_STRAW**)**. The system operates in a similar method to indoor beef fattening and utilises lambs (males and female not kept as replacements) transferring from the intensive sheep dairy sector (e.g. Roquefort, Manchego). Weaned lambs enter the system at approximately 1 week of age and initially fed milk replacer, but rapidly introduced to concentrates and then fed a total mixed ration (TMR) of 40% maize silage and 60% concentrate @1.2kgDM/day, growing at ~380g/day and reaching a slaughter weight (46kg liveweight) at around 120-130 days of age (Helander et al., 2015). Indoor feeding means methane inhibitors can be fed with a 29% reduction in enteric methane (Martínez-Fernández et al., 2014), and manure collected for biogas production. The same precision feeding technologies used in intensive beef finishing can be used here also.

Feed no Food

This storyline sees sheep meat production confined to permanent pasture areas of Europe. Whilst additional forage may be available through temporary forages within cropping systems, this is likely utilised for monogastric protein extraction or prioritised for dairy cows. Meat sheep production is likely confined to existing systems in Western and Northern UK and Ireland where large flocks of ewes graze meadows and natural rough grazing land, based on MS_NO_UPLAND as a baseline system. Smaller, hardy adapted breeds, producing 1 lamb per year, graze predominantly natural/unimproved grasslands at low stocking rates. They are often hefted during the summer months on hills and mountains and then in the winter and for lambing, are brought down to lower altitude, improved or semi-improved in-bye land. This offers shelter to the flock during harsh weather and for outdoor lambing. Around lambing when ewes have extra nutrient requirements, grazing is supplemented by hay and possibly silage made on the lower lying land during the summer months. Lambs are either finished on grass or forage root crops if suitable land it available or sold as stores to finish on forage leys and catch crops in a mixed cropping (as described in the EF storyline).

In Southern Europe a similar system exists utilising upland semi-natural pastures and scrubland, with hardy ewes producing around 1 lamb per year, based on MS_SO_HAY. Ewes graze hills and mountains, often with transhumance in parts of southern France, central and northern Spain, Italy and across to Greece. Ewes are hardy native breeds bred for reliance on a wide range of forage species. Lambs are reared by their mothers and sold for slaughter at weaning, which may be at various times of the year depending on the region.

High Animal Welfare

This storyline is based on the extensive grazing systems of Northern Europe (e.g. mountains/hills of Scotland, Wales and Northern England) and the mountainous regions of Southern France/Northern Spain. These systems are characterised by small, hardy breeds which are adapted to extensively grazing natural and permanent grasslands over summer at low stocking rates (0.5-2 ewes per ha (Matthews et al., 2012). Breeding ewes are relatively unproductive, producing only 1 lamb each per year but have excellent mothering ability. In winter ewes are brought down from the mountains and hills to fields that provide shelter (hedgerows and trees) and have access to shelter (e.g. barns) if they choose to use it (Piirsalu et al., 2020). Lambing occurs at grass (in-bye fields, but again with access to housing by choice) in the spring, poor grass growth at this time could be supplemented with good quality hay or silage to address heightened ewe energy requirements in late pregnancy/early lactation. Intervention in the lambing process is low. Low stocking rates at pasture mean ewes and weaned lambs can selectively graze a diverse range of plant materials and intestinal parasite challenges tend to be small. Ewe lambs are mated as yearlings and will lamb for the first time as 24-month-olds. Natural weaning will occur at around 16 weeks of age, and replacement rates are around 20% (AHDB, 2025). Young animals not required as breeding replacements can be reared to slaughter weight on the farm if sufficient good quality feed is available or sold as store lambs to be finished on improved grass. Transport times would be minimised in this instance. Closed flocks (except for the purchase of breeding rams) and excellent biosecurity mean disease challenges are minimised, vaccinations are used where available to prevent known disease challenges. Reduced parasitic gastroenteritis risk due to low stocking rates, means traditional tail docking (for hygiene purposes), and castration of lambs is not conducted as a matter of course and where necessary (to maintain hygiene and prevent unwanted mating) should be done using local anaesthetic.

Sheep dairying

The steps to identify the main dairy sheep systems are shown in Sheep dairying system baseline construction in the appendix. The synthesis process identified 2 main dairy sheep system clusters, as shown in **Error! Reference source not found.**, with sub-systems. The extensive system cluster covered a range of c ountries and systems as shown in Table 9

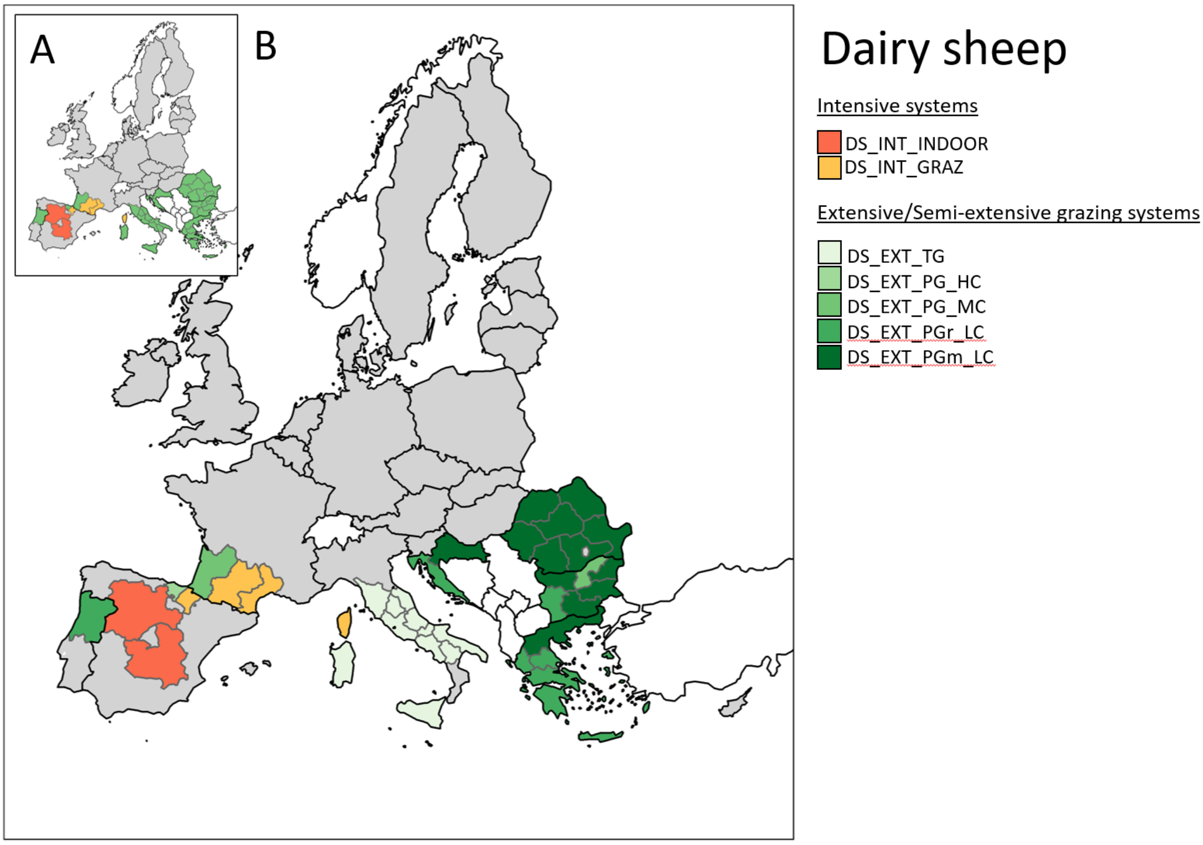

Figure 8 Dairy sheep systems

A: Map representing the general systems. B: Map representing the systems. The colours of Map B are explained in the legend. The underlined titles are the names of the general systems; the colours refer to the systems.

Table 9 Description of the dairy sheep systems

System	Herd size (dairy ewes)	Main breed type	Milk yield (kg ewe^{-1})	Roughage		Concentrates (kg sheep year^{-1})	Grazing days
				Summer	Winter		
DS_INT_INDOOR	1000 (FADN: 770 ± 210)	Dairy type	400	Alfafa hay		270	0
DS_INT_GRAZ	480 (FADN: 400 ± 110)	Dairy type	320	Hay, grazed grass (3 months)	Grass silage, hay (9 months)	230	85
DS_EXT_TG	250 (FADN: 230 ± 80)	Dairy type	200	Grazed grass (6 months)	Grass hay, grass silage (6 months)	NA	300
DS_EXT_PG_HC	380 (FADN: 270)	Dairy type	230	Grazed grass, grass silage (7 months)	Grass silage, grass hay (5 months)	180	280
DS_EXT_PG_MC	330 (FADN: 290 ± 0)	Native	195	Grazed grass (7 months)	Grass hay (5 months)	125	285
DS_EXT_PGr_LC	200 (FADN: 220 ± 100)	Native	200	Grazed grass, hay (4 months)	Grazed grass, hay (8 months)	30	365
DS_EXT_PGm_LC	20 (FADN: 200 ± 70)	Native	NA	Grazed grass (8 months)	Grass hay, alfafa hay (4 months)	20	290

BASELINE SYSTEMS

Intensive indoor dairy sheep

The intensive indoor dairy system was identified in central Spain and Italy. It is also based on large dairy breeds including the Lacaune or Assaf, with some extremely large flock sizes in Spain (>1000 ewes). Feeding is largely based on alfalfa hay, compound feeds and at least in Italy also some maize silage. The milk yield is like the French intensive system, with concentrate feed usage lower in Italy than Spain.

Intensive grazing dairy sheep

The intensive grazing system was identified in southern France and Corsica, comprising large Lacaune breed flocks based on temporary and permanent grasslands. The system has limited grazing days and relies on grass hay or silage for indoor feeding, together with a high level of concentrates.

Extensive dairy sheep systems

The extensive main dairy sheep cluster could be sub-divide into four specific systems. All four sub-systems comprise extensive grazing, with native breeds and milk yields of up to 230 litres per ewe. The French Pyrenees system includes transformation of the milk to cheese, whilst the eastern European system comprises small flocks, more akin to subsistence farming. The Italian and French systems utilise a little maize, but all systems are based on grass for grazing and hay or silage winter feed.

FUTURE SYSTEMS

The future dairy sheep systems were developed and described in the following sections.

Efficiency First

A future dairy sheep system based on the efficiency first storyline would be based around large scale (700+) intensively managed ewes (e.g. Assaf or Lacaune breeds) kept indoors and in a similar manner to the most advanced systems in Western and Southern Europe. Ewes would lamb 5 times in 3 years (averaging 3 lambs/ewe/year (Gonzalez-Ronquillo et al., 2025)), with lambs sold for fattening at 4-7 days old. Age at first lambing is reduced to 12 months (Vouraki et al., 2025). The continuously housed ewes' diet would consist of a high level of concentrate use (460 kg as fed/ewe (Gonzalez-Ronquillo et al., 2025)) as part of a total mixed ration including maize silage, leguminous forages and cereals. The ration would also include feed additives to inhibit enteric methane production, with an expected impact of ~29% reduction in enteric methane (Martínez-Fernández et al., 2014). Breeding would be improved using precision technology for the aid of oestrus identification and artificial insemination, whilst monitoring of health status would be automated and linked to temperature control and improved air quality in buildings. Milk yield would be at the highest level of today's performance achieved through recording and breeding selection programs (average 360kg+ per lactation (Vouraki et al., 2025)).

Feed no Food

Under this storyline, sheep dairying would be confined to pasture areas of the Alps, Pyrenees and Southeastern European areas where small ruminants have traditionally been kept. With the exclusion of concentrate feeds, ewes are maintained by grazing in the summer and either hay in the winter in upland areas or moved to lowland areas for over-wintering outdoors (transhumance is commonplace in these systems ('Overview of Sheep Production Systems', 2017). The forage-based diet provides adequate nutrition for lower yields (140kg/ewe/lactation (Pulina et al., 2018)) . Ewes lamb for the first time at 18 months of age (A Greener World UK, 2021), to allow for slower growth on forage only diets, and produce 1-2 lambs per year depending on breed. Replacement milking ewes can either remain with their mothers for 25 days (peak milk at 28-49 days, Morris, 2017) at which point they continue to be artificially reared until being weaned onto pasture at a minimum of 6 weeks of age (A Greener World UK, 2021), or removed at birth and artificially reared to maximise saleable milk yield. Lambs not being kept as replacement are removed after birth and sold or artificially reared for sale at heavier weights through a meat sheep system.

High Animal Welfare

In this storyline sheep dairying is considered semi-intensive, it utilises grazed pastures like those described in the FnF storyline, however, higher milk yields are supported through supplementary concentrate feeding. Breeds must be selected for their ability to thrive in the climatic conditions of the farm but also be suited to predominantly pasture-based free ranging system – dual purpose breeds may also be suitable. Yields similar or slightly higher than the FnF storyline are achievable though maternal lamb feeding will reduce the amount of saleable milk. Ewes will not lamb before 18 months of age (A Greener World UK, 2021) and ewes will produce 1-2 lambs per year depending on the breed. Lambs should remain with their mothers in the flock until weaning naturally (not before 12 weeks of age). All other aspects of managing the sheep flock should be the same as the HW storyline for meat sheep.

Goats

The steps to identify the main goat systems are shown in Goat system baseline construction in the appendix, and this process identified 4 main goat system clusters, as shown in Figure 9, described subsequently, with key variables sourced from all data sources highlighted in Table 10.

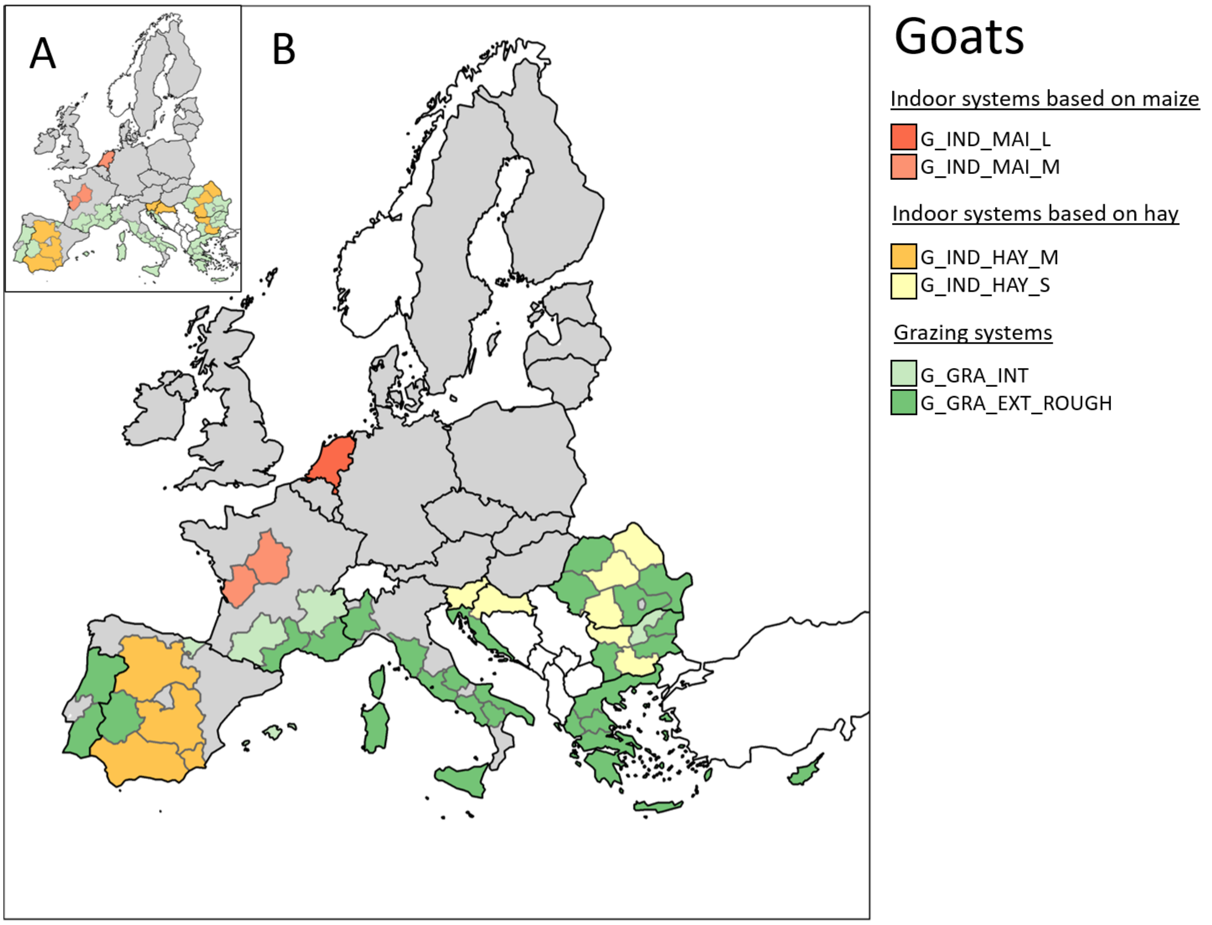

Figure 9 Goat systems

A: Map representing the general systems. B: Map representing the systems. The colours of Map B are explained in the legend. The underlined titles are the names of the general systems; the colours refer to the systems.

Table 10 Description of the goat systems

System	Herd size (goats)	Breed type	Milk yield (kg goat^{-1})	Roughage		Concentrates (kg goat year^{-1})	Grazing days
				Summer	Winter		
G_IND_MAI_L	1000 (FADN: 350)	Dairy type	1000	Grass silage, Maize silage		650	0
G_IND_MAI_M	350 (FADN: 480 ± 60)	Dairy type	850	Grass hay, maize silage		310	0
G_IND_HAY_M	350 (FADN: 730 ± 140)	Dairy type	500	Alfafa hay		400	0
G_IND_HAY_S	50 (FADN: 130 ± 40)	Dairy type	650	Grass hay, Alfafa hay (9 months)		300	0
G_GRA_INT	100 (FADN: 310 ± 120)	Dairy type	700	Grazed grass, hay (5 months)	Hay, cut grass (7 months)	300	150
G_GRA_EXT_ROUGH	100 (FADN: 260 ± 120)	Dairy_low productivity	250	Grazed grass (8 months)	Grazed grass, hay (4 months)	150	320

BASELINE SYSTEMS

Indoor maize fed goats

The indoor maize system was identified in the Netherlands (very intensive) and western France and (intensive). Both systems are characterised by high inputs and high milk yields, based on an indoor, maize silage and grass hay system. Some systems also use zero grazing and carry cut fresh grass.

Indoor hay fed goats

The indoor hay fed system extends across the Mediterranean and farms can be specialist dairy goat or be more mixed with cropping, providing homegrown concentrates. The hay can be grass or also alfalfa with its higher protein content and drought resilience. Milk yields are variable and depend on the level of intensity of feeding but are usually lower than the maize-based systems.

Intensive grazing goats

The intensive grazing goat system was identified across multiple countries, but mainly in France (Midi-Pyrénées), on quite small farms, with specialist dairy goat breeds and an intermediate milk yield of 700 litres per year.

Extensive grazing goats

The extensive goat systems were identified across the Mediterranean, with these systems relying on native breeds, with grazed grass and hay the main forages and an extensive grazing season. Milk yields are low, reflected in the low level of concentrate feeding compared to the more intensive systems. These systems are often based on access to common grazing lands that require herding skills to optimise grazing/browsing and for daily milk collection.

FUTURE SYSTEMS

The future goat systems were developed and described in the following sections.

Efficiency First

This storyline is based on two pedo-climatic zones, a northern one based in Netherlands and a southern one based in Spain. In NW Europe large (e.g. 1100+ goats), high yielding, indoor intensive systems are based on high breeding such as the Saanen which in the most efficient systems yield 1500L/doe/year (Berezhnoy, 2025). Based on the experience and practices of intensive dairying in the Netherlands, these systems use high levels of technology such as AI, sexed semen and embryo transfer, confinement rearing and intensive health and productivity monitoring (Miller & Lu, 2019; Pulina et al., 2018). Mortality of the milking herd is relatively low at 2.7% (Dijkstra et al., 2023), with the milking herd housed in intensively managed in barns with straw bedding, and fed a mix of grass silage, hay, maize silage, alfalfa and concentrates (2-2.5 kg/goat/day - precision feeding of TMR based on yield (Berezhnoy, 2025)). Prolonged lactation is common (600 days) with kidding only for replacement (does yield 10,000L in 2 or 3 lactations). The first kidding @ 12 months, and second kidding at 2 or 3 years is often followed by continuous/prolonged lactation (Berezhnoy, 2025). Kids (twins) are removed shortly after birth, fed colostrum, then reared on powdered milk for 5-7 days at which point they are sold for meat production. Only 50% of herd are used for breeding, with a 20% replacement rate typical. There is a high use of vaccines and strict biosecurity for disease prevention. Because the animals are housed permanently, methane inhibitors can be used in the diet and waste used for bio digesting energy.
The southern European intensive goat dairying operation is based on the G_IND_HAY_M baseline data. This would reflect the increasing intensity of Spanish dairy goat operations typical in Andalusia, that house their Murciano-Granadina breed goats all year around and manage to optimise milk production. Milk production per goat could increase to 800kg (Castel et al., 2010), though reliance on externally sourced concentrate feed would increase due to feeding of ~500kg per doe to accompany the alfalfa hay typically grown within an arable cropping rotation. Improvements in recording and management of individual animals would

accelerate with the use of precision livestock to aid breeding, culling and physiological monitoring, such as demonstrated by the Eskardillo system (Belanche et al., 2019).

Feed no Food

This storyline is based on grass fed dairy goat systems, like those found in Western France. These systems rely on predominantly fresh grazed grass (improved grassland), supplemented with conserved forages such as hay, grass silage and straw. Without concentrate supplementation yields from mainly alpine breeds, would be expected to be around 2.5kg milk/goat/day. Extended lactations are uncommon with typical lactation length being 305 days (Laurent et al., 2023). The average number of lactations is 3 and approximately 20% of the herd are replaced annually (Laurent et al., 2023). As with the EF system, kids (twins) are removed shortly after birth (Vickery et al., 2023) and artificially reared to an age at which they can be sold for meat production (5-7 days). Only replacement young stock are kept on the farm. Artificial Intelligence (AI) and sexed semen are used to speed up genetic gain within the herd. Milking goats are at pasture most of the year, with housing confined to the colder winter months.

High Animal Welfare

This storyline is based on the same as that described for the FnF storyline in terms of having a forage-based diet, however the composition of pastures grazed should be diverse to satisfy the generalist nature of these grazers (Temple & Manteca, 2020). Stocking rates should be low enough to reduce competition for food and associated stress, but at a level that pasture diversity and quality is not compromised. Lower yielding (2kg/goat/day) adapted breeds (e.g. Alpine breeds in France) are common in these systems. They are reliant on mainly grazed forage but with some concentrate input to ensure an adequate body condition score year-round (particularly during early lactation). The milking herd must always have access to shelter (from heat and cold) and if housed during the colder winter months, must be able to access the outdoors. Housing at kidding will reduce neonatal losses from hypothermia and predation, helping reduce pre-weaning losses in kids from an average of 20% in extensive systems (Dwyer et al., 2016) to <10%. Kids (twins) are reared at foot until natural weaning at 8-10 weeks of age – 25% of small ruminant's total milk yield is produced in the first 30 days of lactation (McKusick et al., 2001), resulting in a significant reduction in saleable milk yield from this system. Roughage should be available to kids from their first week of life to support rumen development. Natural mating should be used, but as with the AW dairy sheep system, male and female animals should be kept in stable groups to prevent unwanted mating.

Pigs

The steps to identify the pig systems are shown in Pig system baseline construction in the appendix. For the pig system analysis, it was not possible to differentiate between breeding and finishing systems in the Eurostat and FADN databases, but the survey allowed experts to describe these systems separately. The synthesis process identified 4 main pig system clusters, as shown in Figure 10 described subsequently, with key variables sourced from all data sources highlighted in Table 11 (breeding) to Table 12 (finishing).

Synthesis

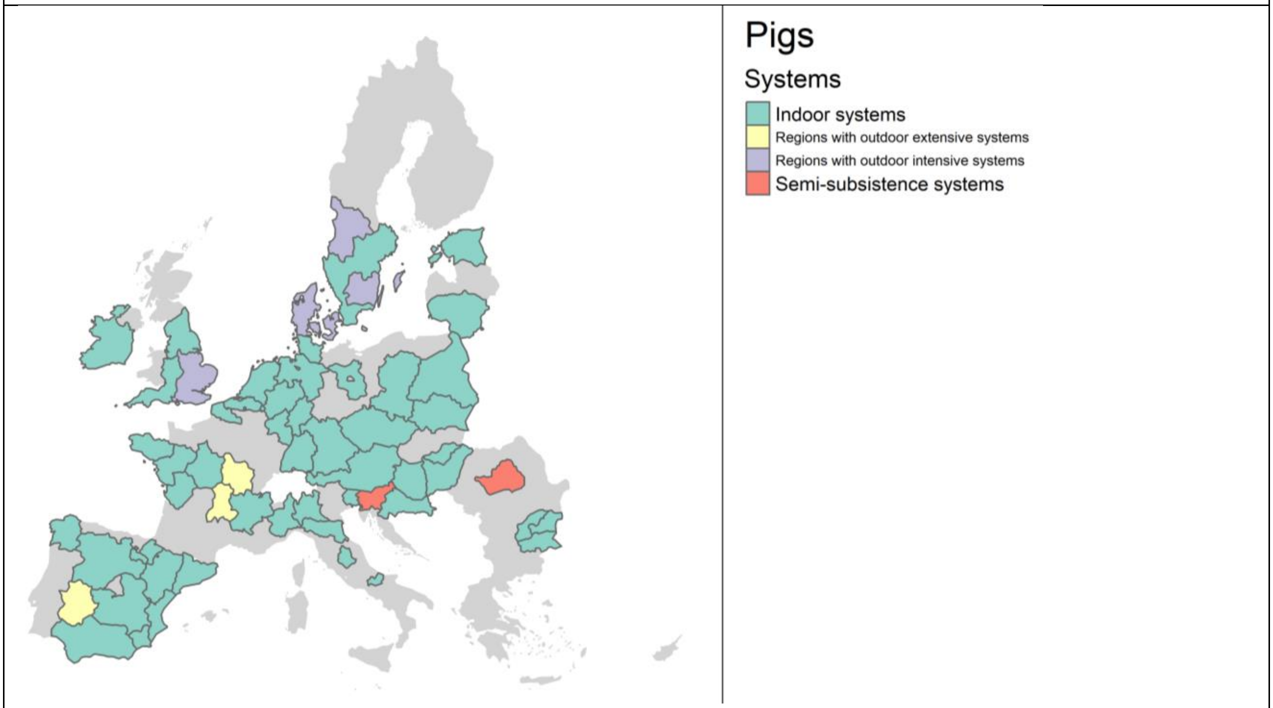

Figure 10 Pig systems

Table 11 Table summarizing the average data for each pig breeding systems

System	Herd size (sows)	Breed type	Piglets weaned (# sow cycle^{-1})	Breeding cycles (# annum^{-1})	Concentrates (kg sow year^{-1})	Housing type	Grazing days
Indoor conventional systems	200 (FR) - 1000 (FADN: 350)	Large white or Cross bred (DK)	13 - 15	2.3-2.5	1200 - 1500	Indoor slatted or part slatted	0
Outdoor intensive systems	50 (FR) - 1000	Large white or Cross bred	10 - 12	1.3 (FR) - 2.4 (UK	1500 - 1600	Outdoor huts	365
Outdoor extensive systems	No data	No data	No data	No data	No data	No data	No data
Semi-subsistence systems	1	Large white	10	2	500	Indoor with outdoor run	250

BASELINE SYSTEMS

Indoor intensive pigs

The indoor conventional pig breeding system is visible across the EU, but varies considerably in its size of operation, as the survey data highlighted. Feeding varied between 1200-1500 kgs per sow per annum, with 2.3-2.5 cycles per annum common. The farm size is less important as indoor systems do not require land use, except for spreading slurry waste. The pigs are usually specialist large white or cross-bred and confined to crates for farrowing and typically the whole lactation. Piglet mortality was still generally at around 15% for the indoor systems, though less than for outdoor breeding systems.
The indoor conventional pig finishing system is seen across the EU and may reach the size of >2000 finishers. Feeding varied between 250-330 kgs per finisher with growth rates of 0.6-1.1 kg per day. Housing is usually entirely indoor with restricted light and at least part slatted floors connected to underfloor slurry systems. Through literature we differentiated the standard pig system finishing pigs at ~110kg liveweight, and the heavy pig systems, typical of Italy where they are reared longer to a weight of ~170kg liveweight to meet the requirements of the Parma ham PDO certification.

Outdoor intensive pigs

The intensive outdoor pig systems are common in northern Europe, such as in the UK and Denmark. This system was also noted in France but mainly for small herds compared to the large herds of up to 1000 sows further north. Feeding levels seems to be slightly higher, whilst the number of cycles is lower and piglet mortality higher. This type of production can be conventional or organic but is still quite intensive for both, and usually reliant on external feedstuffs. The outdoor pigs are usually part of the rotation on arable farms (owned or rented), usually sown as temporary grass, with the manure incorporated. Sows are usually housed in individual huts with extensive use of electric fences.

The intensive outdoor finishing systems have slightly lower growth rates than the indoor systems and are usually specialised units producing organic or labelled pork. Housing is usually indoors with an outdoor concrete-based run that may have for example a rooting area.

Table 12 Table summarizing the average data for each pig finishing system

System	Herd size (pigs)	Breed type	Liveweight gain (kg day^{-1})	Sale weight (kg liveweight)	Concentrates (kg finisher)	Housing type	Grazing days
Indoor conventional systems	1000 - 2000	Large white or Cross bred (DK)	0.82 (FR) - 1.1 (UK)	110 (UK) - 120 (FR), 170kg (IT)	250 (ES, UK) - 290 (FR), ~500kg (IT)	Indoor slatted or part slatted	0
Indoor finishing of outdoor intensive systems	400 (FR) - 800 (DK)	Large white or Cross bred	0.64 (FR) - 0.92 (DK)	110 (UK) - 120 (FR)	250 (ES, UK) - 290 (FR)	Indoor with outdoor run	0
Outdoor extensive systems	Variable	Native	No data	No data	No data	No data	224
Semi-subsistence systems	3	Large white	?	110 (UK) - 120 (FR)	250 (ES, UK) - 290 (FR)	Indoor with outdoor run	0

Outdoor extensive pigs

The extensive outdoor pig systems may exist in many European countries, but the Dehesa region in Spain/Portugal and forest systems such as Auvergne or Corsica in France are well known but we were unable to collate a full dataset for either of these systems. The finishing systems are in the same regions as the breeding sows, whilst housed in outdoor huts and receive some concentrate feed in addition to foraged feeds including the traditional acorns. The daily growth rate also appears lower, though it is unclear how much nutrition they receive from foraging, and this varies according to the specific system and labelling.

Semi-subsistence pigs

Within eastern Europe, farmsteads with 1 sow and lower concentrate use were identified. These systems typically use an outdoor run system with conventional breeds, rearing 1 cycle per year of piglets through to slaughter. These systems use concrete pens with some bedding and are fed a similar level of concentrates as other systems.

FUTURE SYSTEMS

The future pig systems were developed and described in the following sections.

Efficiency First

Within the EF storyline, intensive indoor pig production systems would make further efficiency gains across all components, extending performance beyond existing best practice. Within the breeding phase, piglet mortality will be reduced from the 20% stillborn or dying in first five days (Stygar et al., 2022), through improved disease prevention (e.g. vaccinations), performance and health monitoring systems, feed formulation and building design/environment (Stygar et al., 2022). Breeding advances and selection will continue to result in improved sow performance, combined with improved sow health monitoring, building environment and feeding, resulting in productivity gains (weaned piglet weight per year). With these improvements, sows will be averaging 40+ weaned piglets per year (compared to the current Danish indoor sow average of 33.9 (Mateos et al., 2024).

Feed use would be reduced per output, with less reliance on existing high-quality proteins (including soy) and more use of processed (biorefined or digested) byproducts such as rapeseed meal to improve nutrient availability (Mateos et al., 2024). Through the use of improved genetics and individual pig precision feeding technologies, overall, feed conversion efficiency would improve by up to 20% compared to today (Mean FCR in French pig farms: weaner-fattener 1.68kg/kg; fattener 2.8kg/kg and breeding sow 3.0kg/kg (Gaillard et al., 2020). Through improved building design and manure management, gaseous emissions would be significantly reduced, with 80-90% reductions in ammonia and methane captured for bioenergy use.

Feed no Food

Under the FnF storyline conventional pork production would reduce greatly, as the sector currently relies on high levels of food products as the primary nutrition source. Within the FnF storyline, pig production would now be limited to existing regions of extensive outdoor production such as south-western Spain and central Portugal, as well as very limited indoor production in previously intensive production regions such as Brittany, Denmark, Germany and northern Italy. The extensive pig systems would continue to be based around the existing system, with the Dehesa agroforestry system central to the nutrition of the pigs.

However, the breeding phase may be impacted by reduced conventional feed availability, so some reduction in numbers would be expected. Productivity would be similar to existing extensive systems with finishing to around 1 year of age based on acorns and foraging.
The remaining conventional pig system diets would now be based on a combination of food industry byproducts, supplemented with high quality forages. Feeds would include rapeseed meal, brewers or distillers grains, sugar beet pulp, graded-out vegetables, in addition to limited quantities of high-quality forages such as clover grass, alfalfa (Ma et al., 2022), arable silage (~ 20%) or fodder beet (Edwards, 2002). Novel feeds including bio digested byproducts or protein extracted from forages could help replace the current fraction provided by soya meal. Due to the feed changes, productivity would be reduced in both breeding and finishing phases. Finishing animal growth rates would be far below current conventional system levels and may be close to 50% lower due to reduced energy and protein levels in feeds, resulting in considerably longer rearing. Buildings and manure handling facilities would remain like today, though some technological advances may allow for reductions in emissions of ammonia and methane.

High Animal Welfare

A future pig system based around the needs of the animal would be based on an enhanced organic system, based on existing Danish or UK organic/biodynamic systems. As well as reduced stocking density and a relaxation in productivity intensity to allow for less productive but hardier breed choice, the production environment would be enhanced with access to agroforestry elements, such as willow or poplar, or mixed woodland including oak trees to supply acorns. When housing is required, such as during inclement weather, shelters with deep bedded straw would be utilised (Brown, 2015). For rationing, a mixed diet of grains, pulses and beneficial supplements would be offered, as well as areas of root crops such as fodder beet or swedes to encourage natural rooting behaviour, together with lucerne pasture/silage which allows for a lower CP diet (Jakobsen et al., 2015), which is also suitable for more traditional breeds that carcass traits with a higher fat to protein ratio (Edwards, 2002). A more robust breed selection would be associated with lower productivity than modern breeds but allow for litter sizes more akin to wild pigs, with around 8-10 piglets per litter and 1.5 litters per year. Piglet weaning age would be extended beyond the organic norm of 40-56 days to ~90 days, reflecting more natural behaviour, (FiBL, 2023).
Growing and finishing pigs would also be reared in a more welfare friendly manner, with constant access to outdoor areas, including areas of agroforestry and root crops. Feed rations would be similar to the sows and include a wide diversity of grains, pulses and some forage crops such as lucerne for improved digestive tract health. Due to slower growth rates, as with other species, young males may prove problematic and require separate areas to females, as anaesthetised castration would in general be prohibited.

Laying hens

The steps to identify the laying hen systems are shown in Laying hen system baseline construction in the appendix, and this process was only able to identify 2 main laying hen system clusters, as shown in Figure 11. However, due to the expert survey, the usual commercial systems could be further differentiated and are described subsequently, with key variables sourced from all data sources highlighted in Table 13.

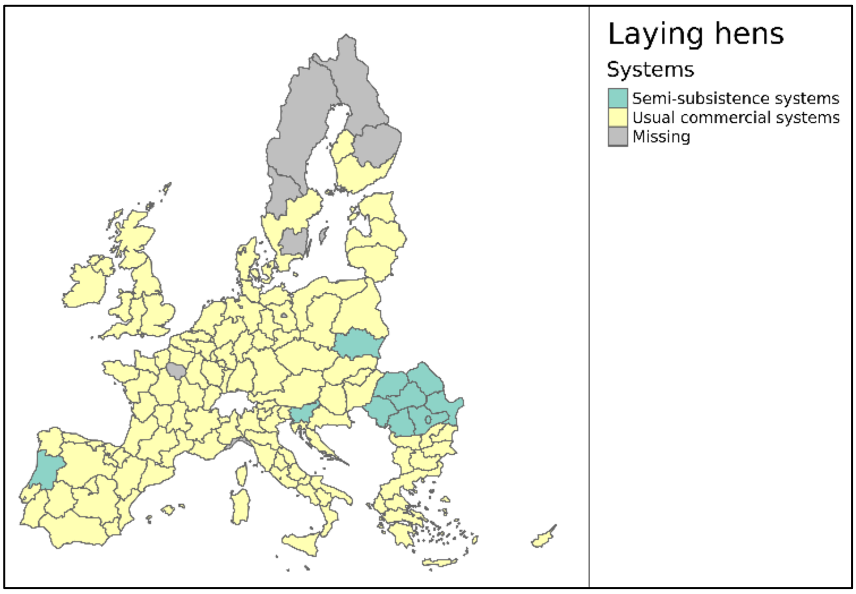

Figure 11 Laying hen systems in Europe, defined through databases and expert analysis.

BASELINE SYSTEMS

Cage laying hen system

The indoor conventional cage system generates the maximum egg production using high output breeds, but with minimal space requirements.

Barn laying hen system

The barn laying system has slightly lower productivity with a similar space requirement and near identical feed use.

Table 13 Table summarising the average data for laying hen systems (mainly from the surveys)

System	Hens (# building^{-1})	Breed type	Egg production (eggs year^{-1})	Concentrate feeds (kg hen year^{-1})	Housing type	Animal density in housing (m2 hen^{-1})	Animal density outside (m2 hen^{-1})
Cage system	?	High output	290 - 340	40 - 46	Indoor caged	0.08	N/A
Barn system	6000 (UK, DE) - 18000 (DK)	High output	279 - 330	40 - 46	Indoor barn	0.08 (DK) - 0.11	N/A
Outdoor systems	5000 (UK, DE) - 18000 (DK)	High - medium output	290 - 335	43 - 46	Outdoor access	0.11	2 (UK) – 4
Outdoor organic systems	3000	High - medium output	270 - 330	45 - 50	Outdoor access	0.17	2 (UK) - 4
Semi-subsistence	20	Dual purposed	280	10	Completely free	0.11	N/A

Conventional outdoor laying hen system

These systems incorporate outdoor access, but internal space allowances are similar, whilst productivity is still high.

Organic outdoor laying hen system

The organic laying hen system requires more space per hen in the barn, whilst outdoor areas remain similar, depending on the certifying body. Organic regulations limit the number of hens per house to 3000, but productivity remains similar.

Semi-subsistence laying hen system

The semi-subsistence laying hen system does not have minimum space requirements, beyond the general minimum, but birds are typically free to roam extensively. Their production is likely lower than the other systems, but hens are usually retained beyond the typical productive lifespan of 55-75 weeks, as is typical in other systems.

FUTURE SYSTEMS

The future laying hen systems are described in the following sections.

Efficiency First

Existing intensive barn layer systems would be further optimised to improve efficiency of production. As with the pig sector, gains in feed conversion efficiency of ~20% would be expected due to a variety of factors including improved specialist genetics, better health and nutrition, use of precision technology and monitoring systems. Furthermore, emissions from the controlled environment buildings will be significantly reduced through pollution control and capture systems. Manure would be processed to produce organic manure with low losses. Feeding and nutrition would be enhanced through better use of existing ingredients as well as further use of byproducts and alternative proteins such as insect meal, as well as additives such as probiotics to improve health. Use of precision monitoring and AI driven analysis and system alerts is already showing improvements in layer performance, for example 3.5% improvements in egg yield, and 1.8% reductions in mortality, (Agri-Tech Centre, 2024). This trend would be expected to continue.

Feed no Food

Under the FnF storyline restrictions on the use of grains and pulses in the diet would strongly restrict the population and production of laying hens. Whilst poultry can utilise a wide range of feeds, the energy and protein density of modern feed mixes is far greater than provided by for example fruit and vegetables that chickens may consume in a natural setting. As scavengers they can also eat animal protein waste, but existing legislation restricts or prevents this (European Commission, 2023), to avoid disease transfer such as ovine Spongiform Encephalopathy (BSE). Therefore, the FnF storyline would involve small flocks fed on locally available byproducts from the food industry, processing side products including rapeseed meal, bran and rejected grains and pulses. Productivity is severely impacted, with assumptions of ~200 eggs per hen per year.

High Animal Welfare

The improved welfare of laying hens would utilise a system closer to their natural environment including agroforestry, diverse land use including pasture with a high diversity of species, grains and pulses, as well as additional feeds for behavioural stimulus. Flocks would be much smaller than conventional systems, with constant outdoor access including a minimum of 10m^2 per hen (Soil Association, 2025), and an environment to stimulate access and discovery within the range. Hens would be a resilient dual-purpose type with numbers linked between the males being reared as broilers and hens retained for laying. Layers would be reared on-farm as pullets to improve adaptation to the system and be retained for two laying cycles, resulting in reduced egg numbers around 170/year (CIWF, 2013). Building space would be specified beyond organic guidelines and include enrichment such as straw bales, adequate water and feeding space per hen. Feeds would include a wide range of grains, pulses and seeds as well as health supporting additives including probiotics and prebiotics and phytotherapy and aromatherapy (Bonnefous et al., 2022).

Broiler

The steps to identify the laying hen systems are shown in Broiler system baseline construction in the appendix, and this process was able to identify 2 main broiler system clusters, as shown in Figure 12. The expert survey was able to describe further systems beyond the databases, with key variables sourced from all data sources highlighted in Table 14.

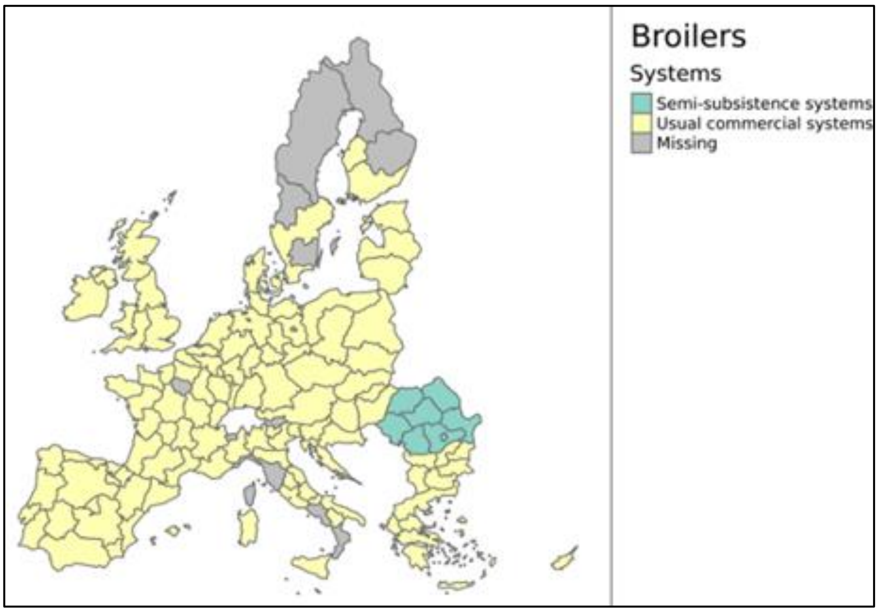

Figure 12 Broiler systems in Europe, defined through databases and expert analysis.

Table 14 Table summarising the average data for broiler systems (mainly from the surveys)

System	Broilers per building (# building-1)	Main breed type	Finishing cycles (# year-1)	Concentrate feeds	Housing type	Animal density in housing (m² broiler-1)	Animal density outside (m² broiler-1)
Indoor systems	30,000 - 60,000	Fastest or Medium growth	5 - 8	3 - 6	Indoor	33 - 42	\
With outdoor access	5,000 - 40,000	Medium or Slow growth	3 - 8	5 - 16	Outdoor access	23 - 27	2 - 6

Organic	5,000 - 25,000	Medium or Slow growth	3 - 8	6 - 15	Outdoor access	18 - 23	2 - 8

BASELINE SYSTEMS

Indoor system

Indoor rearing of broilers is near identical across Europe, with very large systems finishing up to 60,000 birds per cycle, with 5-8 cycles per year. The birds are usually reared to 2.0-2.2 kg at slaughter, with a daily growth rate of 50-60g per day.

With outdoor access system

These systems incorporate outdoor access, but internal space allowances are similar. These systems are usually producing birds to a specific label specification e.g. “Label Rouge” in France) to add value and compensate for the slower growth rates (30-40g per day).

Organic outdoor system

The organic broiler system varies between an intensive organic system similar to the conventional outdoor broiler, or can be a more extensive system, e.g. with moveable sheds on pasture. The organic rules demand more space inside the building and due to the use of slower maturing birds, more feed is required due to a slower growth rate.

FUTURE SYSTEMS

The future broiler systems were developed and described in the following sections.

Efficiency First

Broiler production continues to improve in efficiency and further reductions in FCR of ~20% allow more to be produced from lower inputs. Despite the recent trend for slower growing systems in e.g. the UK and Netherlands, a future EF system is assumed to adopt the fastest growing genetics with efficiency as the main driver, and welfare in terms of mortality may not differ between systems (Torrey et al., 2021). Reduced feed consumption and improved diets with use of refined byproducts and additives including bioactive compounds, can improve carcass composition (Choi et al., 2023). Precision livestock monitoring and feedback systems are assumed to optimise management. Insulated buildings reduce energy inputs (Costantino et al., 2021), while systems including air scrubbers control the production environment and incorporate emissions such as NH_3 and VOC removal (Cao et al., 2022). for better air quality within and outside the production shed. As with laying hens, manure is converted to fertiliser to reduce emissions during storage and application and avoid mineral fertiliser use.

Feed no Food

Due to the extreme reliance of the broiler sector on grains and pulses (food) it is unlikely this sector would exist beyond small scale, backyard chicken types of production. Whilst some feed byproducts are suitable for poultry it is assumed that competition for these products would be great and priority is given to pigs and laying hens, with the only poultry meat output being that of culled laying hens.

High Animal Welfare

Whilst achieving great efficiency gains, the broiler sector suffers from welfare issues, and an HAW system would vastly change the production system. Slow growing, e.g. 0.04kg day^{-1}, (Torrey et al., 2021), more resilient breeds including dual purpose male chicks from the laying industry as well as purpose bred chicks for meat would be reared on-farm. These could include specialist extensive system meat breeds such as Robusta maculata and Kabir chickens, which have been shown to undertake more intense walking activity and foraging behaviour, which improved their antioxidant capacity, though rearing periods could be up to 120 days (Dal Bosco et al., 2021). Production systems based on the most extensive organic/free range systems such as Label Rouge would be employed, with continual outdoor access to diverse pasture including agroforestry. The diet would be designed to enhance health whilst maintaining moderate growth rates, that allow the structural components to support growing muscles and weight. Rations would be based on a variety of grains and pulses and include health supporting ingredients containing phyto and bioactive compounds, as well as the addition of pro and prebiotic components. Each batch per shed would be limited in numbers to around 500 broilers and housing would be mobile units to allow rotation of pasture. Rearing time would be up to three times longer than conventional timings (CIWF, 2013), meaning the number of cycles per year is reduced to around three.

Discussion

Baseline system development

This characterisation of current European livestock production systems utilised different sources including statistics, experts, and literature. A previous study (Dumont et al., 2019) also aimed to characterise the European livestock territories combining European statistical data (a decision tree based on Eurostat database) and qualitative data from experts (using the Barn tool). This previous study considered all livestock together as a sector. The characterisation for PATHWAYS went further by developing a description for each livestock category, and by using more variables, hence more detailed information. This characterisation also combined information across scales, connecting farm-level information and territorial information for use within multiple work packages.

USE OF TWO EUROPEAN DATABASES: EUROSTAT AND FADN

For characterising European livestock systems, the European databases Eurostat and FADN have the advantage that they cover all regions of the European Union at different scales. Eurostat provides aggregated data from the Farm Structure Survey at a regional level (e.g. the percentage of permanent grasslands in the region, the number of head of a certain livestock class for all farms). The FADN public dataset assesses a much smaller sample of commercial farms and provides data publicly for different farm types (e.g. average percentage of permanent grasslands for a dairy farm in the region). Thus, while Eurostat gives a wider picture of the territory, FADN provides better information of commercial farm operation per specified economically defined farm type.

However, the two databases do not have the same coverage. Whilst all farms are considered in the Eurostat FSS database, for the FADN database sampled farms must exceed a minimum economic size criteria in order to be representative of “commercial farms” defined as ‘a farm which is large enough to provide a main activity for the farmer and a level of income sufficient to support his or her family’ (EC, 2020). Thereby, in some countries, small-scale farms may be excluded if they are not considered as commercial farms according to the definition above, and even if they can play a significant role in rural development (Veveris et al., 2019). Moreover, FADN allocates farms to farm types according to their speciality defined by several conditions on the total standard output in economic terms of the holding. Consequently, mixed farms with a livestock enterprise (e.g. dairy cows) are not included in the specific farm types (e.g. specialist dairy) whereas livestock in these mixed farms are accounted for in Eurostat data (e.g. dairy farms). As a result, Eurostat accounts for all livestock in Europe for a characterisation of livestock systems, while FADN data is focused on fewer larger farms. Furthermore, the public FADN data at regional level is limited to few farm types which often combine different species (e.g. “Specialist granivores” includes both pigs and poultry, or Specialist cattle includes both beef suckler cows and all growing cattle) which complicates the process of characterisation.

Therefore, analysing these two European databases allowed us to cross check and consolidate the results across scales and differences of coverage and farm type definition at regional level. However, the use of European databases at NUTS2 level only shows the regional tendencies. Thus, the heterogeneity of systems within a region is not represented, therefore, only trends can be shown for the tendency of agricultural production within a region. Whilst individual farm data is available upon request from FADN, previous experiences within the GenTORE project found that, despite the detail provided, small sample sizes often prevent a thorough analysis (due to the minimum sample size of 15 according to FADN rules of use). Therefore, less common system types, e.g. organic, can only be published at for example national or large region level, so local specificities are also lost in the analysis.

In summary, whilst Eurostat provides data at territorial level and FADN gathers mainly economic data (Kelly et al., 2018), these two databases provide a general overview of systems at regional or farm type level, they both lack the specific data related to farm practices linked to specific livestock enterprises, which are needed for a characterisation of a livestock system as noted by Borghino et al., (2021). Specifically, whilst using database information worked relatively well for the ruminant sector to link their main ration source (due to their link to land use on the same farm), for the monogastric sector, the lack of connection to on-farm land-use prevented the identification of different systems such as free range versus housed systems. Therefore, we also sought information from livestock experts in different countries and with different livestock sector experience.

ADVANTAGES AND LIMITS OF EXPERTS AND LITERATURE

Interviews with experts and using literature provided more detailed information concerning practices in different systems. This is especially of relevance for example in ruminant systems to identify the main feeds in summer and winter, all systems regarding the level of outdoor access, and for poultry to identify the use of cages etc. Furthermore, experts were able to highlight specificities, such as understanding the connection between the systems, including the export of weaned calves from France and Romania to Italy and Croatia respectively. Experts and literature also allowed the interpretation and cross-checking of analysis of the European statistics databases. However, even though a high number of systems were described by experts, the process is complex and time-consuming which leads to a lower coverage of European countries in comparison to European databases. Indeed, out of the 27 EU countries + the United Kingdom, the FADN covered 25 countries whereas with the survey, complete system descriptions were collected from only 11 countries. Moreover, the coverage of the survey was biased by a low representation of Eastern and Central European countries (only Romania and Croatia). In addition to this bias of geographic representativeness, calling on experts introduces another bias linked to the individual subjectivity based on their specific expertise and experience. Indeed, for a specific country and animal category, the survey was usually only completed by one expert who was usually an academic.

SYNTHESIS PROCESS

The synthesis of baseline system data aimed to represent the diversity highlighted at European level but limit the number of systems characterised to maintain an overview as these systems are quantitatively modelled within Task 5.2 of PATHWAYS. Combining data from European databases and the survey allowed for complementarity. Indeed, the synthesis enriched the statistical description of clusters with quantitative and qualitative data from experts and literature, and the combination of different clusters help to broaden the scope of the survey data to other European countries. This process of defining the final systems was partly conducted manually, therefore the subsequent validation at an annual meeting provided a final step for cross-checking and validation for each sector.

Future system development

Following the development of the baseline systems, several storylines representing potential transitions for the European livestock sector were developed within WP2 of PATHWAYS. This deliverable aimed at interpreting their general ideas into specific future livestock systems across all the sectors represented. This was achieved by using the most relevant baseline systems as a starting point, expert input through multiple workshops and by drawing upon a wide range of scientific literature and industry knowledge transfer resources.

FUTURE SYSTEMS

The process identified multiple scenarios for all sectors, with common themes within each storyline. The EF storyline favoured the most intensive and efficient current systems including monogastric species, dairy and intensive ruminant finishing systems. Predominantly indoor production allows for greater precision in feeding (including additives), breeding, manure storage and emission control, though trade-offs are negative impacts on animal welfare due to perceived industrialisation, further intensification of livestock dominated regions and conflicting use of food materials.
The FnF storyline emphasised the use of grasslands to support ruminant production and a likely shift away from livestock protein in agricultural lowlands as production shifts from feed to food production. Limited technological improvements may support slight reductions in emissions and improvements in labour productivity, but yields are likely to reduce with the withdrawal of concentrate feeds from dairy and intensive beef production.

The HAW storyline focused on the needs of the animals and adopted an organic or biodynamic approach to production, resulting in a much-reduced intensity of production, especially for monogastric systems, but also for intensive ruminant production. Extended weaning and reduced growth rates with hardier, more resilient breeds allows more natural behaviours such as extended grazing seasons, later first birthing age and less rick of deformities such as seen in rapidly growing broilers for example.

The future storyline systems will be quantitatively assessed through Task 5.2 of PATHWAYS and compared. It is anticipated that each storyline will have improvements, but also trade-offs between indicators and can help inform the development of future transition scenarios for each sector. Furthermore, it is anticipated that this large resource of current and future livestock system can act as dataset for use by other researchers and projects.

Conclusions

The main livestock systems in Europe were identified and characterised using European databases, expert interviews, and literature. While databases provided structural and land use data, expert input was essential for detailed husbandry information, especially in monogastric systems. The approach aligned with the holistic goals of the PATHWAYS project by integrating environmental, economic, and husbandry data across different scales and data types. The resulting characterisation offers both a simplified overview for territorial modelling and detailed system descriptions for farm-level and economic assessments.

Future livestock system development built on baseline descriptions to align with the various PATHWAYS storylines. Some of the most relevant baseline systems were adapted using the storyline narratives, literature, and industry data. Efficiency First systems focus on developing beyond the most efficient current practices; Feed no Food systems avoided human-edible feed, leading to major changes, especially in monogastric and intensive ruminant systems; and High Animal Welfare systems followed organic and biodynamic husbandry principles. These descriptions support upcoming modelling tasks to assess the sustainability of each transition pathway. Overall, both the baseline systems based on current evidence and the projected potential future systems provide a basis for the PATHWAYS and other projects to build an evidence base for sustainable agrifood policy development in Europe.

Pathways FOR SUSTAINABLE FOOD

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Appendix 1 – Baseline systems from Milestone 11

DAIRY COW SYSTEM BASELINE CONSTRUCTION

The steps to identify the main dairy cow systems are shown in Figure 13.

Analysis of Eurostat data identified five systems, ranging from low yielding small herds in Eastern and Southern Europe, through to high yielding intensive maize-based systems in NW regions. The FADN technical data identified four clusters with a lower yield but high use of home-grown feed through to high yielding systems with a low proportion of permanent grassland and a medium level of home-grown feed. The FADN economic analysis identified seven clusters, with farm size (UAA and economic) and labour input (family vs hired) two key variants.

When the database clusters were merged, many system combinations were identified. This was in part due to the high number of clusters for the economic and labour data.

From the expert survey, 24 systems were defined according to the main feed (maize silage, grass silage or both) and then the breed, the type of production (conventional, organic, labelled), the quantity of concentrates and the presence of grazing. All systems feeding cows with maize silage used a high milk yielding breed and were mainly conventional either indoor systems using a high quantity of concentrates (Spain) or grazing systems using less concentrates (France). Systems feeding cows with both maize and grass silage could use a high volume of concentrates and be either conventional (indoor or grazing systems) (Denmark) or organic or could be less intensive with a low quantity of concentrates (organic system in France). Finally, systems based only on grass (grazed grass, cut grass, grass silage or hay) were split between intensive and extensive systems. Intensive grass-based systems used high milk yielding breed and medium to high amounts of concentrates. These systems could be either conventional (indoor or grazing systems) or organic. Extensive grass-based systems used smaller dairy type breed or dual purposed breed and fed the cows with a medium quantity of concentrates (France) to almost no concentrates (Romania). Some of these extensive systems had their production labelled (Pasture for Life in the United Kingdom, PDO Comté in France).

For the synthesis all the data sources were examined, and manually matched for the key parameters, including milk yield, location, primary feed type and socio-economic factors. This process identified six main dairy system clusters, described subsequently. Due to the high availability of variables relevant to dairy cow production it was possible to also identify a number of sub-systems within these main types.

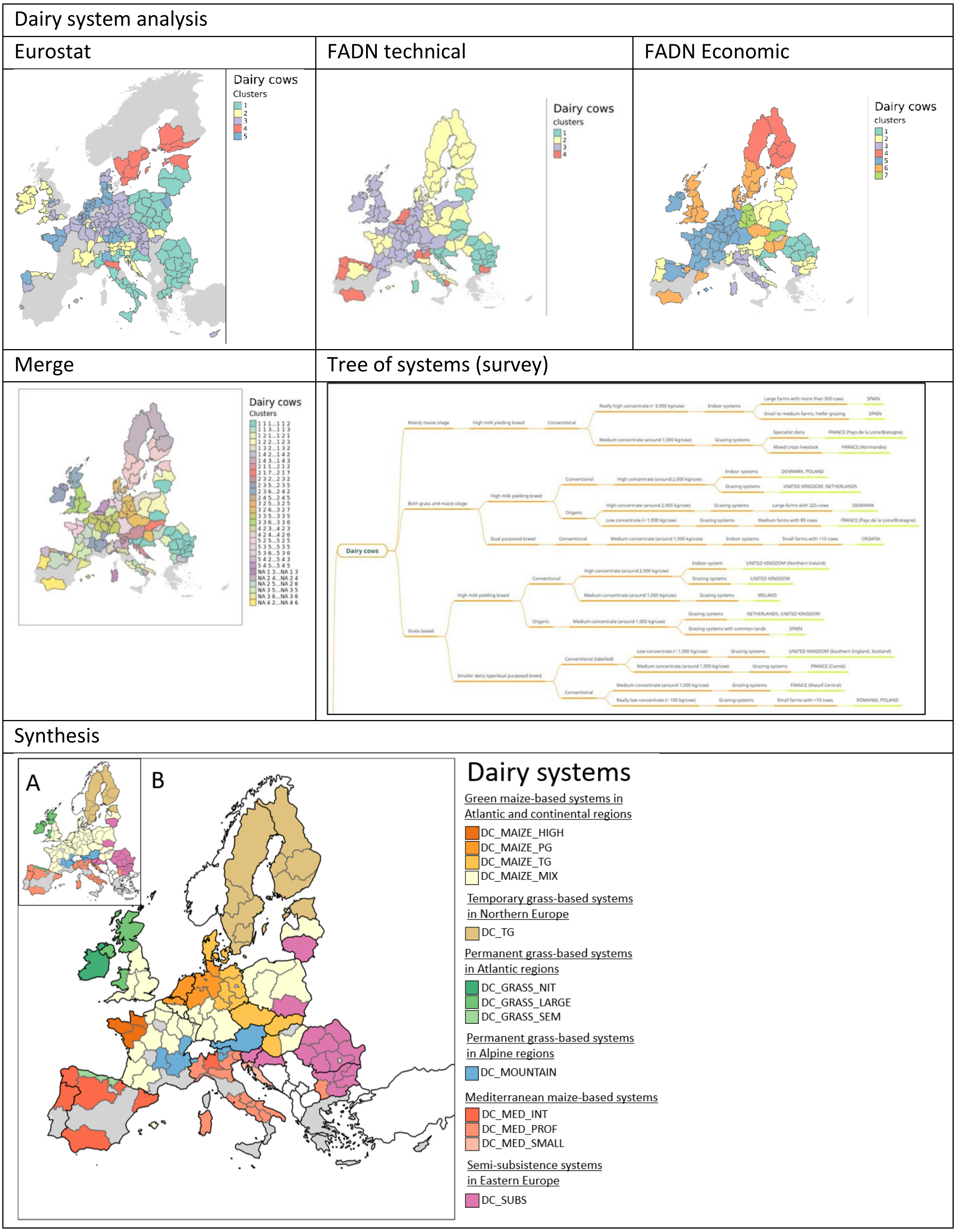


Figure 13 Dairy system livestock classes

SUCKLER COW SYSTEM BASELINE CONSTRUCTION

The steps to identify the main suckler cow systems are shown in Figure 14.

Analysis of Eurostat data identified five systems. The clusters were differentiated by herd size, stocking intensity and grassland types. Scandinavian and central French systems utilise more temporary grasslands, but differ by herd size and intensity, whilst intermediary clusters utilised more permanent grassland. For the FADN analysis, the selection of regions was more complex due to the farm type identifying beef farms, rather than suckler cow or fattening systems specifically. Therefore, extremely high stocking densities, e.g. in the Po valley, Italy and parts of Belgium were excluded, as they were assumed to be cattle fattening regions. This was also manually cross-checked between the more detailed cattle types within the Eurostat region data. The FADN technical data identified three clusters which extended from a high intensity system through to systems with permanent grassland and either a high or low homegrown concentrate level. The FADN economic analysis also identified three clusters, with farm size (UAA and economic) and labour input (family vs hired) two key variants as clusters extended from smaller through to very large.

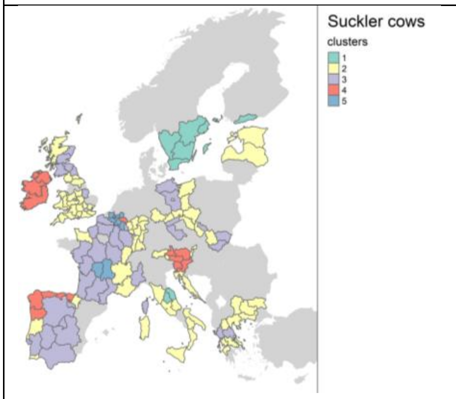
When the database clusters were merged, many system combinations were identified. This was in part due to the high number of clusters for the economic and labour data.

From the expert survey, 23 systems were defined according to the main feed (usually grazed grass, grass silage with hay or occasionally straw) and then the breed, the type of production (conventional, organic, labelled or "regenerative"), the quantity of concentrates, and whether systems sold weaned calves or also finish the cattle on the same farms. Most systems had a high percentage of permanent grassland, though Swedish, Italian and one French system also utilised temporary grasslands for suckler production. Breeds varied from specialised classic beef breeds such as Charolais, through to native local breeds, utilising extensive grasslands. All systems utilised grazed grass, with some not using any concentrate (e.g. PFLA in the UK), whilst others adopted a higher intensity and used a much greater quantity (e.g. French lowland systems). Manure systems were generally for solid waste (with straw bedded livestock), whilst e.g. in UK slurry systems were more common.

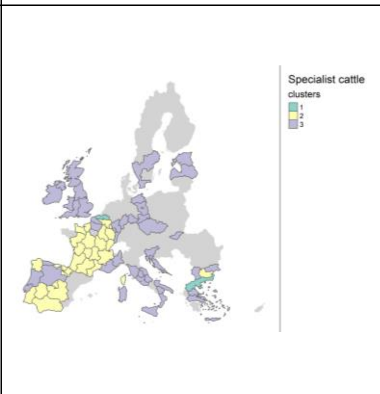
For the synthesis all the data sources were examined, and manually matched for the key parameters, including stocking density, location, primary feed type and socio-economic factors. This process identified five main suckler cow system clusters, shown subsequently, with key variables sourced from all data sources.

Suckler cow systems

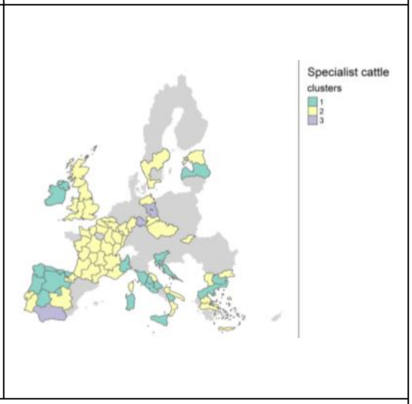
Eurostat



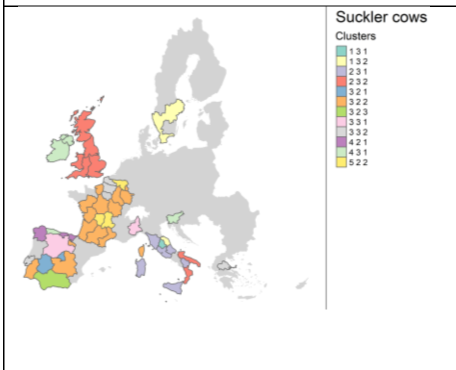
FADN technical



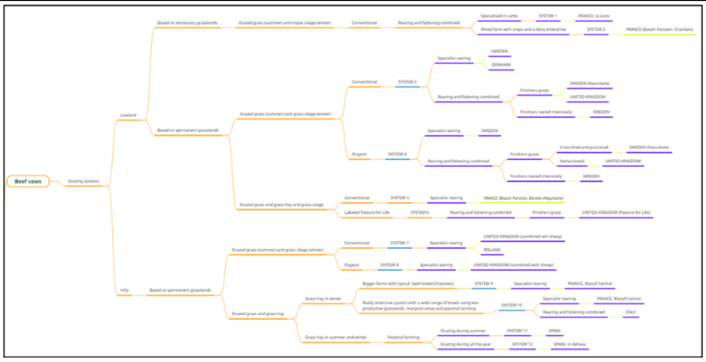
FADN Economic



Merge



Tree of systems (survey)



Synthesis

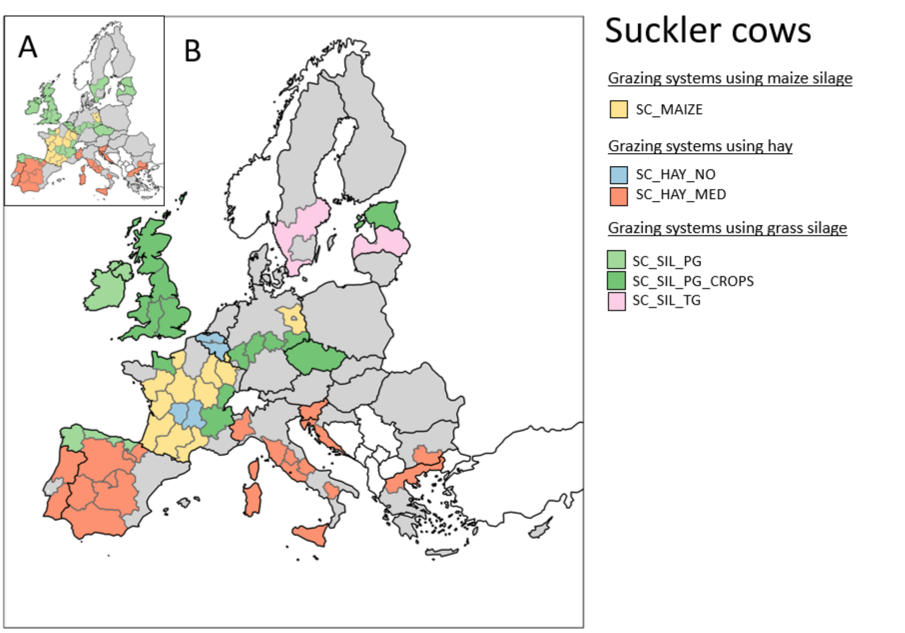


Figure 14 Suckler cow system livestock classes

FINISHING CATTLE SYSTEM BASELINE CONSTRUCTION

The steps to identify the main finishing cattle systems are shown in Figure 15.

Analysis of Eurostat data identified five systems. The clusters were differentiated by herd size, stocking intensity and grassland types. The systems included high permanent grassland systems with low density of holdings, through to high intensity maize and temporary grass systems. For the FADN analysis, the selection of regions was more complex due to the farm type identifying beef farms, rather than suckler cow or fattening systems specifically, therefore manual checks were conducted between the more detailed cattle types within the Eurostat region data. The FADN technical data identified three clusters which extended from a very high intensity system (>4beef LSU/ha), through to systems with permanent grassland and either a high or low homegrown concentrate level. The FADN economic analysis identified four clusters, with farm size (UAA and economic) and labour input (family vs hired) two key variants as clusters extended from smaller through to very large. One cluster was unique to Finland due to a high level of livestock subsidies, which were at very low level in other finishing cattle regions.

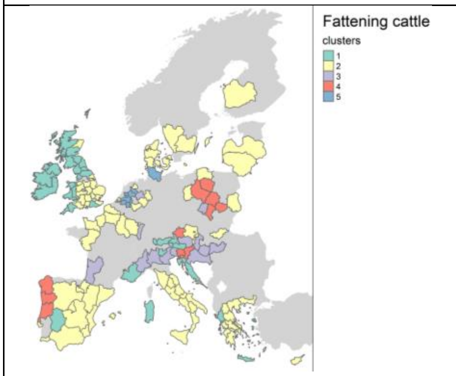
When the database clusters were merged, many system combinations were identified, which were then cross-checked with the survey data described below.

From the expert survey, 18 systems were defined according to the main feed (maize silage, grass silage or both) and then the breed, the type of production (conventional, organic, labelled), the amount of concentrates and the presence of grazing. All systems feeding cows with maize silage used a high milk yielding breed and were mainly conventional; either indoor systems using a high quantity of concentrates (Spain) or grazing systems using less concentrates (France). Systems feeding cows with both maize and grass silage could use a high volume of concentrates and be either conventional (indoor or grazing systems) (Denmark) or organic or could be less intensive with a small quantity of concentrates (organic system in France). Finally, systems based only on grass (grazed grass, cut grass, grass silage or hay) were split between intensive and extensive systems. Intensive grass-based systems used high milk yielding breed and medium to high amounts of concentrates. These systems could be either conventional (indoor or grazing systems) or organic. Extensive grass-based systems used smaller dairy type breed or dual purposed breed and fed the cows with a medium quantity of concentrates (France) to almost no concentrates (Romania). Some of these extensive systems had their production labelled (Pasture for Life in the United Kingdom, PDO Comté in France).

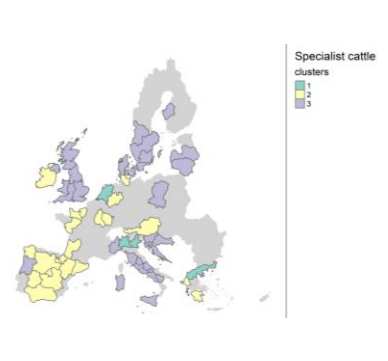
For the synthesis all the data sources were examined and manually matched for the key parameters, including stocking density, location, primary feed type and socio-economic factors. This process identified three main finishing cattle system clusters.

Finishing beef systems

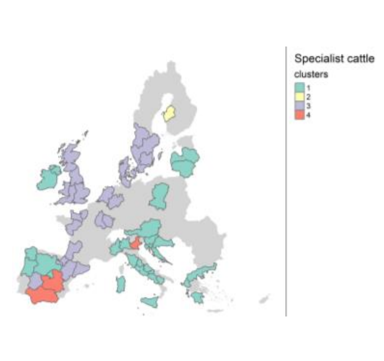
Eurostat



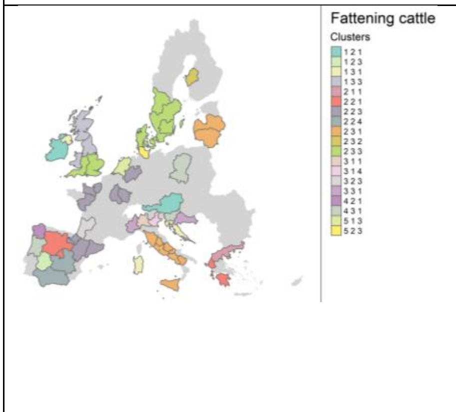
FADN technical



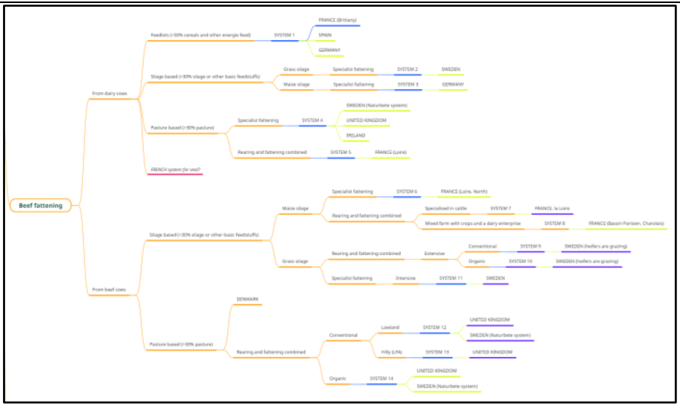
FADN Economic



Merge



Tree of systems (survey)



Synthesis

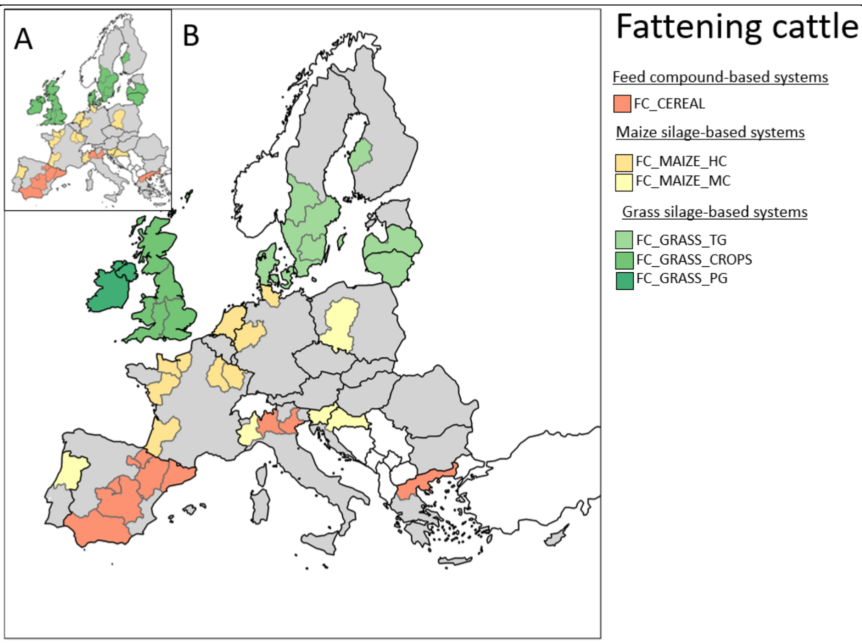
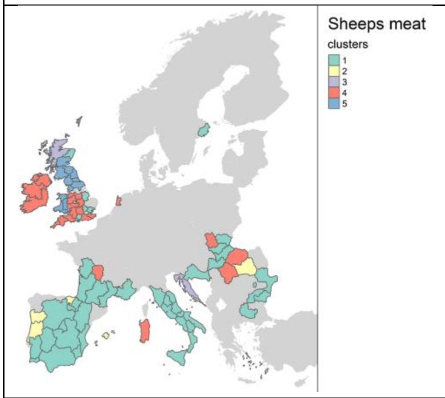
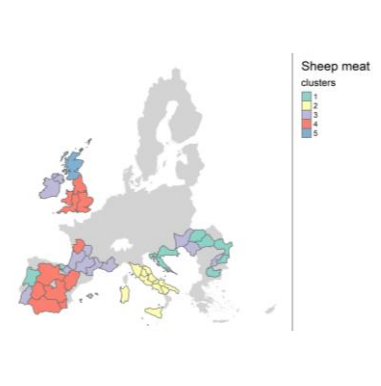
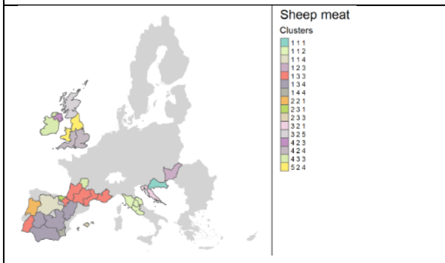
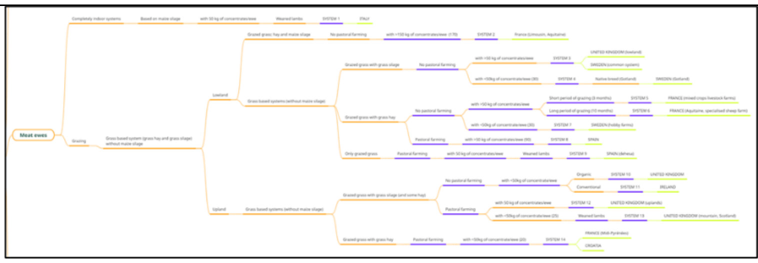


Figure 15 Finishing cattle system livestock classes

MEAT SHEEP (LAMB) SYSTEM BASELINE CONSTRUCTION

The steps to identify the main sheep meat (lamb) systems are shown in Figure 16.
Analysis of Eurostat data identified five systems. The clusters were differentiated by flock size, stocking intensity and grassland types. Cluster 1 was mainly situated in southern Europe, cluster 2 indicated very small flocks, whilst cluster 3 comprised a high % of rough grazing and clusters 4 and 5 comprised larger flocks and higher levels of permanent pasture. For the FADN analysis, the selection of regions was more complex due to the farm type identifying all small ruminant farms. Therefore, the regions selected for FADN analysis were based on the identified Eurostat regions (which include more specific livestock classes), and this identified four clusters. Cluster 1 had a lower level of permanent grassland, but greater use of homegrown concentrates, whilst the other clusters indicated greater permanent grassland. Cluster 4 had a much higher stocking density with clusters 2 and 3 intermediate. The FADN economic analysis identified five clusters, with farm size (UAA and economic) and labour input (family vs hired) two key variants as clusters extended from smaller (1) through to very large farms and flocks in cluster 5, covering Scotland. When the database clusters were merged, many system combinations were identified. This was in part due to the high number of clusters for the economic and labour data.
From the expert survey, 17 systems were defined, according to the geographical situation (lowland, hill etc), intensity, the length of grazing season and winter feed, and the type of production (conventional, organic), the quantity of concentrates and the presence of grazing. The location varied from lowlands, such as in Spain and France, through to hill or mountain in UK and France, which also affected the choice of breed and intensity of production. Therefore, concentrate feeding was quite varied (20 up to 170 kg per ewe), as was productivity, ranging from <1 lamb per ewe up to almost 2. Systems also varied considerably by the weight of lambs produced, suiting the local market.
For the synthesis all the data sources were examined and manually matched for the key parameters, including stocking density, location, primary feed type and socio-economic factors. This process identified six main meat sheep system clusters.

Eurostat	FADN technical	FADN Economic
		

Merge	Tree of systems (survey) – (see also lamb fattening in appendix)
	

Synthesis

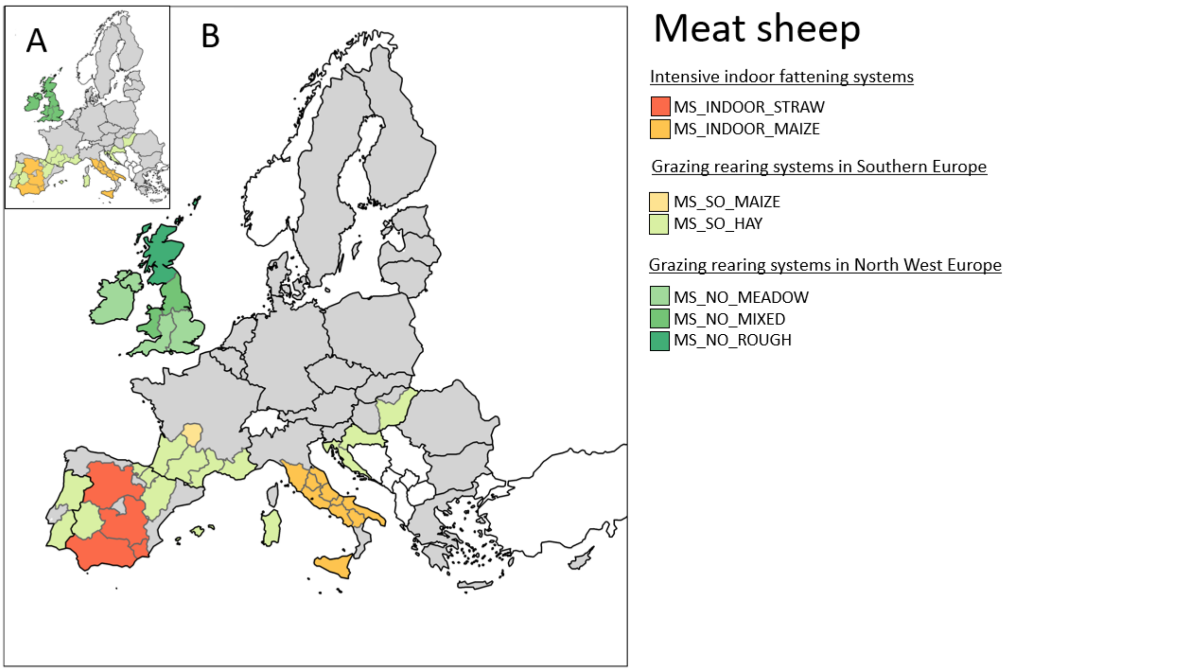


Figure 16 Sheep meat (lamb) systems

SHEEP DAIRYING SYSTEM BASELINE CONSTRUCTION

The steps to identify the main sheep meat (lamb) systems are shown in Figure 17.
Analysis of Eurostat data identified five systems. The clusters were differentiated by flock size, stocking intensity and grassland types and were all geographically in the south or east of Europe. Cluster 1 was mainly situated in Spain with a larger flock size but less specialisation for milk, the other clusters indicated smaller flocks, but greater specialisation for dairy, and varied by the proportion of rough grazing. For the FADN analysis, the selection of regions was more complex due to the farm type identifying all small ruminant farms. Therefore, the regions selected for FADN analysis were based on the identified Eurostat regions (which include more specific livestock classes), and this identified three clusters. Cluster 1 had a higher proportion of homegrown feed, whilst cluster 3 had the highest portion of permanent grassland level and cluster 2 had the highest stocking density of sheep. The FADN economic analysis identified 4 clusters, with farm size (UAA and economic) and labour input (family vs hired) two key variants as clusters extended from smaller (1) through to very large farms and flocks in cluster 4, in central Spain.
When the database clusters were merged, many system combinations were identified, though most of Italy was a single cluster combination.
From the expert survey, nine systems were defined according to the geographical situation (lowland, hill etc), intensity, the length of grazing season and winter feed, and the type of production (conventional, organic), the milk yield, quantity of concentrates and the presence of grazing. The location varied from lowlands such as Spain, through to hill and mountain situations in e.g. France and Italy. The systems varied in intensity, with breeds and concentrate feeding level reflecting this. The milk yields were <200 to 400 litres per ewe, with the highest yielding systems indoor based, and lower yielding utilising poorer land. The main feed is either grazed or ensiled grass, with one lowland system using maize silage and alfalfa was used in Spain.
For the synthesis all the data sources were examined and manually matched for the key parameters, including stocking density, location, primary feed type and socio-economic factors. This process identified four main dairy sheep system clusters.

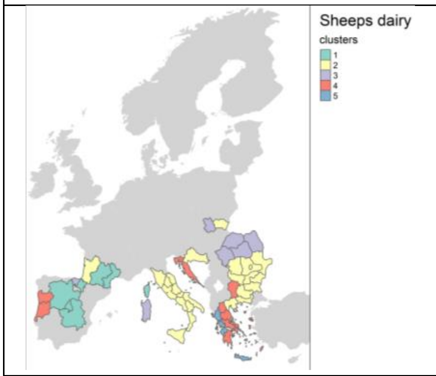
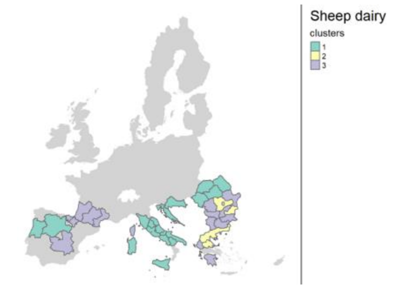
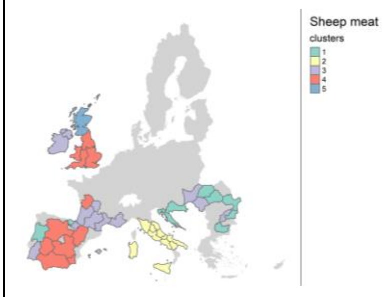
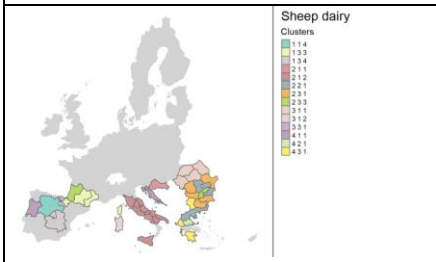
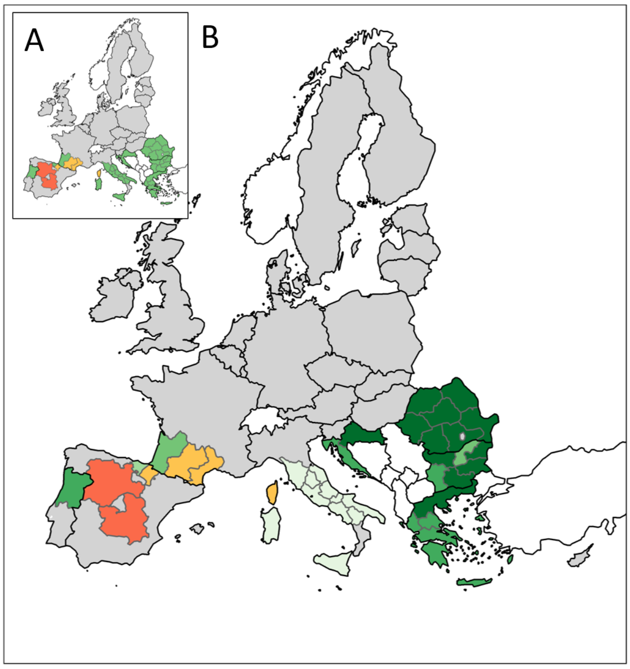
Eurostat	FADN technical	FADN Economic
		
Merge	Tree of systems (survey) – (see also lamb fattening in appendix)	
		
Synthesis (main types)		
	Dairy sheep Intensive systems DS_INT_INDOOR DS_INT_GRAZ Extensive/Semi-extensive grazing systems DS_EXT_TG DS_EXT_PG_HC DS_EXT_PG_MC DS_EXT_PGr_LC DS_EXT_PGm_LC	

Figure 17 Sheep dairy systems

GOAT SYSTEM BASELINE CONSTRUCTION

The steps to identify the main sheep meat (lamb) systems are shown in Figure 18.
Analysis of Eurostat data identified four systems. The clusters were differentiated by herd size, stocking intensity and grassland types, but it was not possible to separate dairy and meat goats (unlike sheep). Cluster 1 is a noticeable cluster in NW France and the Netherlands, with larger herd sizes. Cluster 4 was in central Portugal and Greece Spain with a many smaller flocks and greater rough grazing proportions. Clusters 2 and 3 are intermediate with 3 having a high proportion of rough grazing. For the FADN analysis, the selection of regions was more complex due to the farm type identifying all small ruminant farms. Therefore, the regions selected for FADN analysis were based on the identified Eurostat regions (which include more specific livestock classes), and this identified four clusters. Cluster 1 had a highest stocking density, whilst 2 had the lowest proportion of permanent grassland and 3 and 4 were differentiated by their use of homegrown concentrates (4 was highest). The FADN economic analysis identified six clusters, with farm size (UAA and economic) and labour input (family vs hired) two key variants as clusters extended from smaller (1) through to very large farms and flocks in cluster 6.
When the database clusters were merged, many system combinations were identified, though Italy was almost a single combination.
From the expert survey, 14 goat systems were defined. These were mainly dairy goat systems, with two meat systems defined in Italy and Spain. The systems were defined according to the geographical situation (lowland, hill etc), intensity, the length of grazing season and winter feed, and the type of production (conventional, organic), the milk yield, quantity of concentrates and the presence of grazing. The location varied from lowlands such as France, Spain and Netherlands, through to hill and mountain situations in e.g. Spain, France and Italy. The systems varied in intensity, with breeds and concentrate feeding level reflecting this. The milk yields were <200 through to >1200 litres per doe, representing a vast range in system specification. The highest yielding systems were indoor based, utilising grass or maize silage, whist others graze for most of the year, probably on poor land quality. and lower yielding utilising poorer land.
For the synthesis all the data sources were examined and manually matched for the key parameters, including stocking density, location, primary feed type and socio-economic factors. This process identified six main goat system clusters.

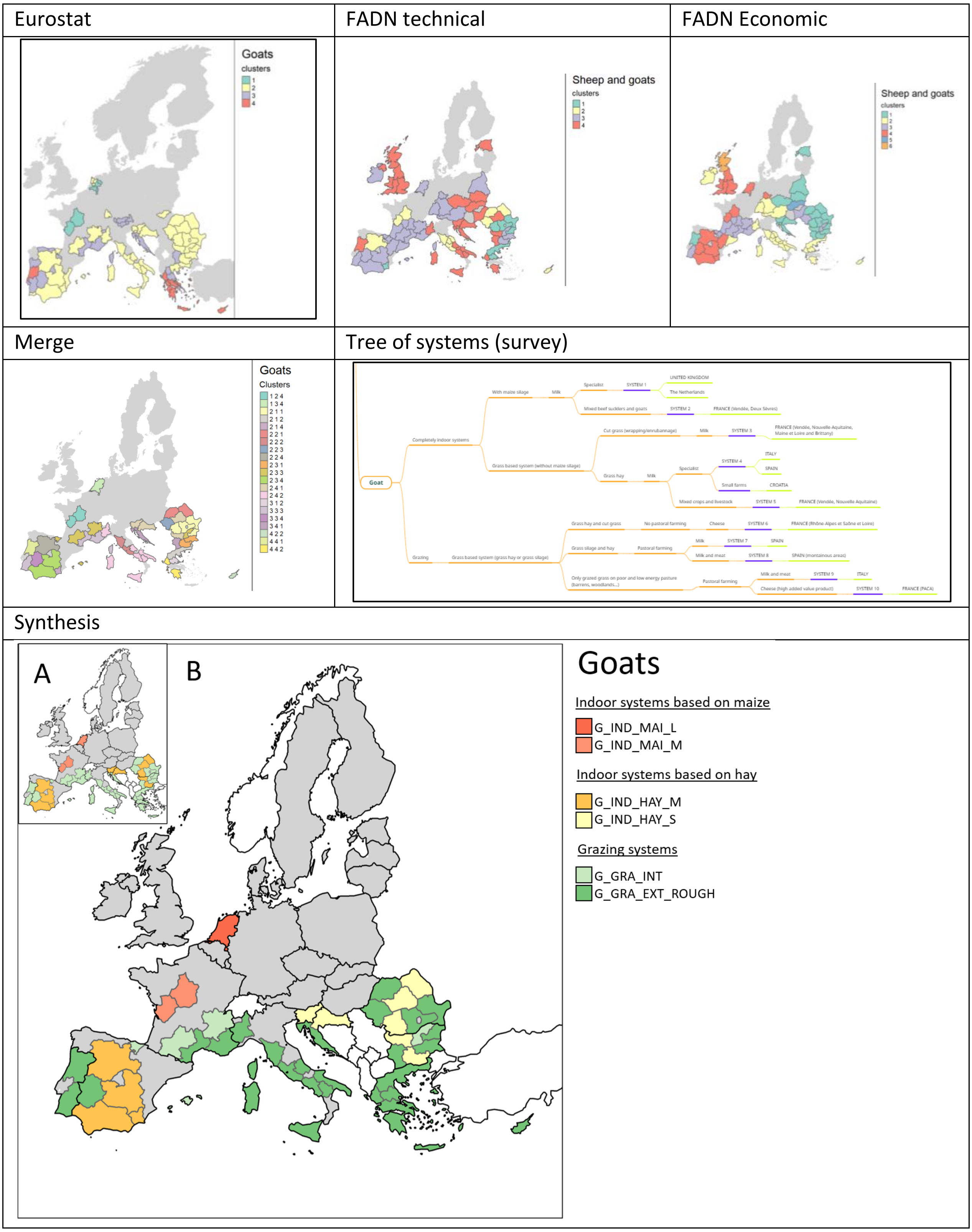


Figure 18 Intensive indoor dairy goat systems with grass hay

PIG SYSTEM BASELINE CONSTRUCTION

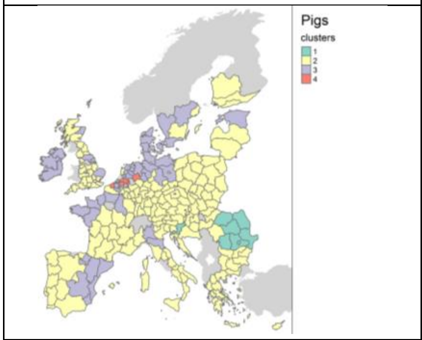
The steps to identify the pig systems are shown in Figure 19. For the pig system analysis, it was not possible to differentiate between breeding and finishing systems in the Eurostat and FADN databases, but the survey allowed experts to describe these systems separately.

Analysis of Eurostat data identified four systems. Cluster 1 are regions of subsistence pig keeping, whilst cluster 2 covered a wide area with a low density of pig holdings. Cluster 3 identified large herd sizes, but only moderate holding intensity, whilst cluster 4 identified specialised pig regions with high stocking density and large herds, such as in the Netherlands. For the FADN analysis, the selection of regions was more complex due to the farm type identifying all monogastric farms together. Therefore, the regions selected for FADN analysis were based on the identified Eurostat regions (which include more specific livestock classes), and this identified five clusters. Cluster 1 was differentiated by their high use of homegrown concentrates, whilst cluster 5 identified as very high intensity systems in Ireland. Cluster 3 indicated pigs and grassland and 4 was a high intensity region. The FADN economic analysis again identified a high number of seven clusters, with farm size (UAA and economic) and labour input (family vs hired) two key variants. Clusters 1 and 2 were small farms, cluster 3 had a high output in Italy, cluster 4 was intermediate, whilst cluster 5 had larger herds with little land, cluster 6 also had larger land area and cluster 7 was small farms with high labour. When the database clusters were merged, many combinations were identified.

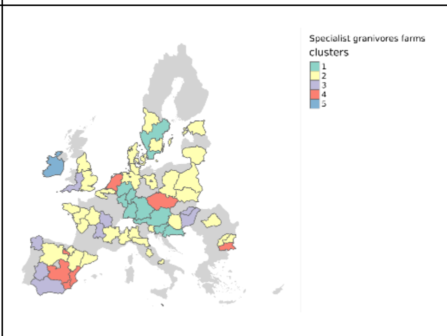
From the expert survey, 20 breeding systems and 21 finishing systems were defined according to the type of housing, intensity of production (cycles, growth rates), the type of production (conventional, organic), the quantity of concentrates and the presence of outdoor production. The breeding systems were typical indoor, intensive systems, with a few examples of outdoor production in e.g. UK and Denmark (even for conventional production). Nearly all systems use modern breeds, with many still use crates for the entire lactation, whilst others have moved to less restrictive crate use, e.g. free- farrowing. The systems usually operate at 2-2.43 cycles per annum, with a few exceptions in less intensive systems, whilst piglet mortality was variable 10-30%, depending on indoor/outdoor systems and country. The finishing systems were described similarly, with indoor production systems the norm. The outdoor systems were limited to organic or speciality labels, or very extensive systems such as Dehesa or forest grazing systems. The feeding level was very similar, as were the finishing weights, with growth rates varying between 0.6 and 1.1 kg per day. In the indoor systems there were differences, such as slatted vs bedded floors, access to daylight, or outdoor runs, as well as the linked manure systems.

For the synthesis all the data sources were examined and manually matched for the key parameters, including stocking density, location, primary feed type and socio-economic factors. This process identified four main pig system clusters.

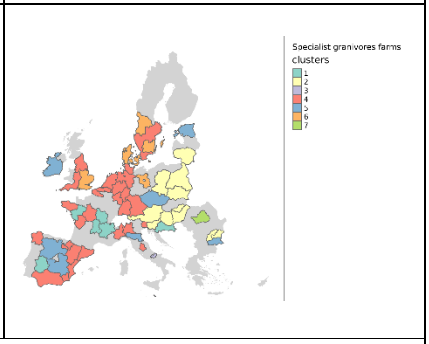
Eurostat



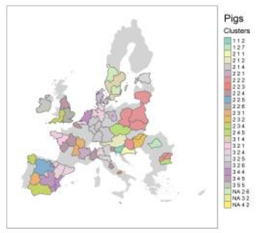
FADN technical



FADN Economic



Merge



Tree of systems (survey) – see also pig fattening tree in appendix

Synthesis

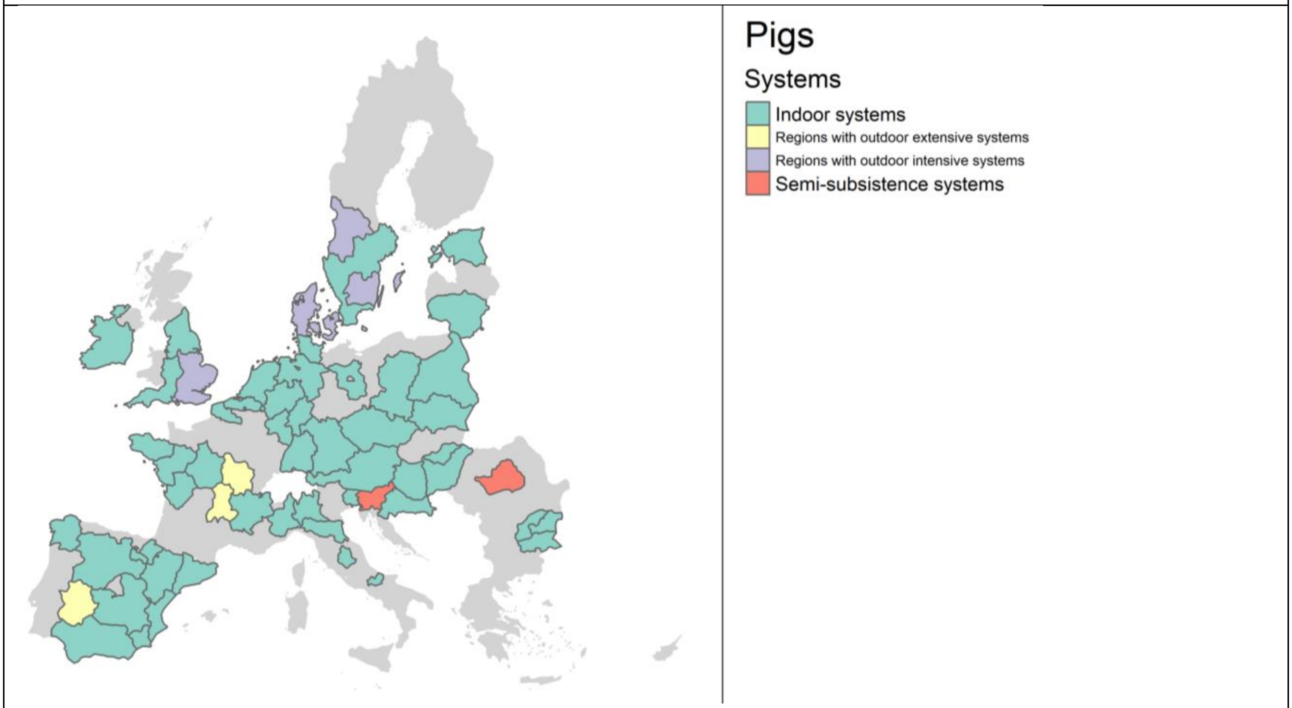


Figure 19 Pig systems

LAYING HEN SYSTEM BASELINE CONSTRUCTION

The steps to identify the laying hen systems are shown in Figure 20. For the poultry system analysis, it was not possible to differentiate between laying hen and broiler systems in the FADN databases, but the survey allowed experts to describe these systems separately.

Analysis of Eurostat data identified 4 systems. Cluster 1 are regions of semi-subsistence poultry keeping, whilst cluster 2 covered a wide area with a low density of poultry holdings. Clusters 3 and 4 were identified for high and very high poultry density. For the FADN analysis, the selection of regions was more complex due to the farm type identifying all monogastric farms together. Therefore, the regions selected for FADN analysis were based on the identified Eurostat regions (which include more specific livestock classes), and this identified 4 clusters. Cluster 1 showed more mixed farming with cattle and pigs and a higher permanent grassland area, whilst cluster 3 was an intermediate cluster and cluster 4 was identified for its greater use of homegrown concentrates on mixed holdings. The FADN economic analysis identified 4 clusters, with farm size (UAA and economic) and labour input (family vs hired) two key variants. Cluster 1 was characterised by a high employed labour input, cluster 2 was intermediate for variables, cluster 3 was identified as having a high output to input ratio indicating high value products in Italy, whilst cluster 4 identified larger farms with some pigs as well as poultry.

Due to the common data between poultry sectors a formal data merge was not undertaken.

From the expert survey, 22 laying hen systems were defined according to the type of housing, intensity of production, the type of production (conventional, organic), the quantity of concentrates and the presence of outdoor production. The egg systems included the old caged system, barn systems, free-range (with outdoor access), though to semi-subsistence systems allowing full free-range. The cage systems still operate in many countries, though barn and free-range systems are now more popular. Organic systems are typically similar to conventional free-range, but with slightly lower production, greater space requirements and smaller flocks, however layers are still only used for a single cycle.

For the synthesis all the data sources were examined and manually matched for the key parameters, including stocking density, location and socio-economic factors. This process was only able to identify 2 main laying hen system clusters, shown subsequently.

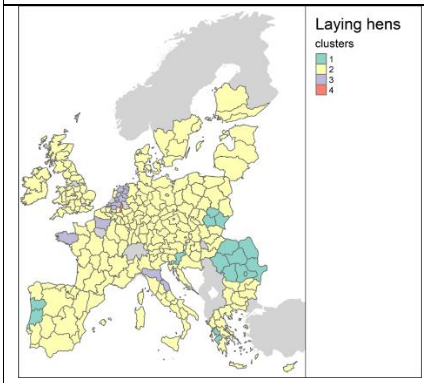
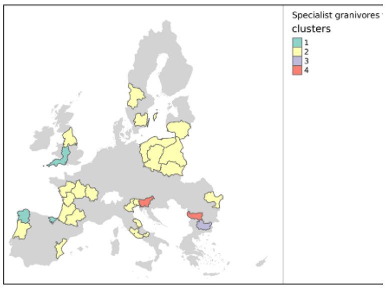
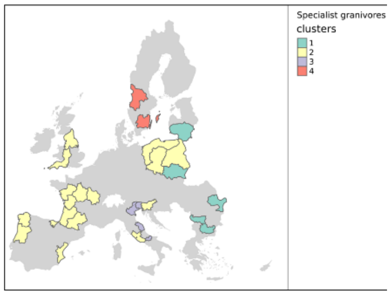
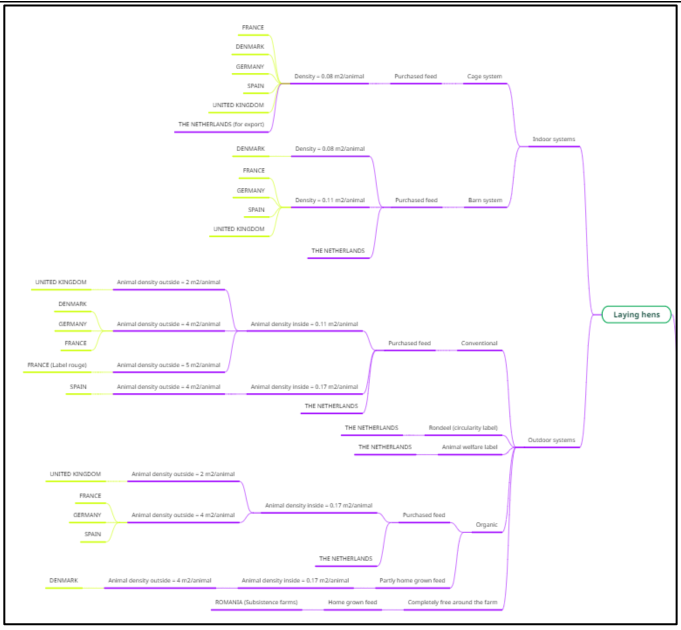
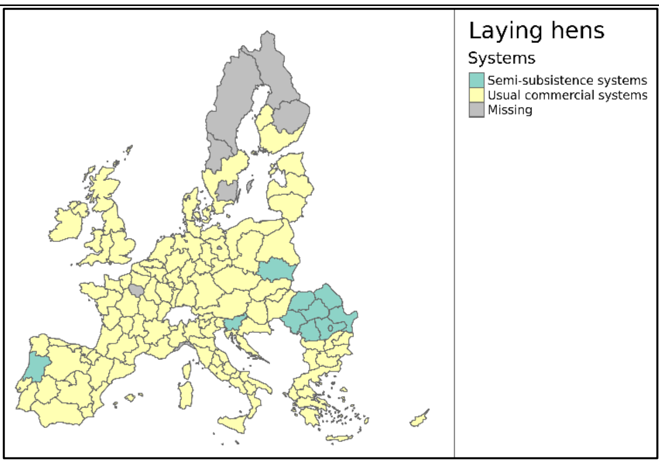
Eurostat	FADN technical	FADN Economic
		
Tree of systems (survey)		
		
Laying hen synthesis		
		

Figure 20 Laying hen systems in European, defined through databases and expert analysis.

BROILER SYSTEM BASELINE CONSTRUCTION

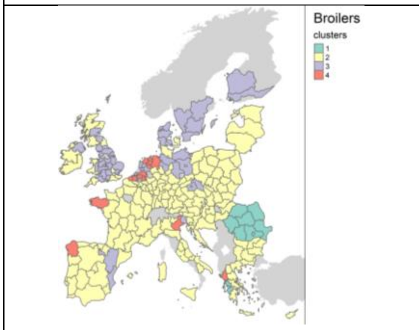
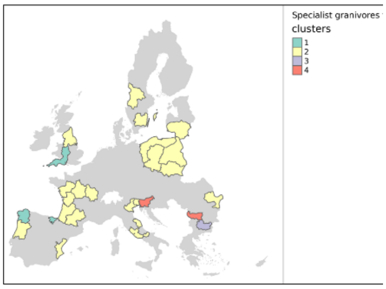
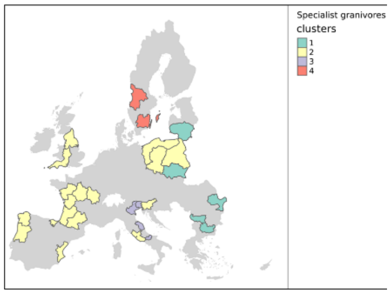
The steps to identify the laying hen systems are shown in Figure 21. For the poultry system analysis, it was not possible to differentiate between laying hen and broiler systems in the FADN databases, but the survey allowed experts to describe these systems separately.

Analysis of Eurostat data identified four systems. Cluster 1 are regions of semi-subsistence poultry keeping, whilst cluster 2 covered a wide area with a low density of poultry holdings. Clusters 3 and 4 were identified for high and very high poultry density respectively. For the FADN analysis, the selection of regions was more complex due to the farm type identifying all monogastric farms together. Therefore, the regions selected for FADN analysis were based on the identified Eurostat regions (which include more specific livestock classes), and this identified 4 clusters. Cluster 1 showed more mixed farming with cattle and pigs and also a higher permanent grassland area, whilst cluster 3 was an intermediate cluster and cluster 4 was identified for it's greater use of homegrown concentrates on mixed holdings. The FADN economic analysis identified 4 clusters, with farm size (UAA and economic) and labour input (family vs hired) two key variants. Cluster 1 was characterised by a high employed labour input, cluster 2 was intermediate for variables, cluster 3 was identified as having a high output to input ratio indicating high value products in Italy, whilst cluster 4 identified larger farms with some pigs as well as poultry.

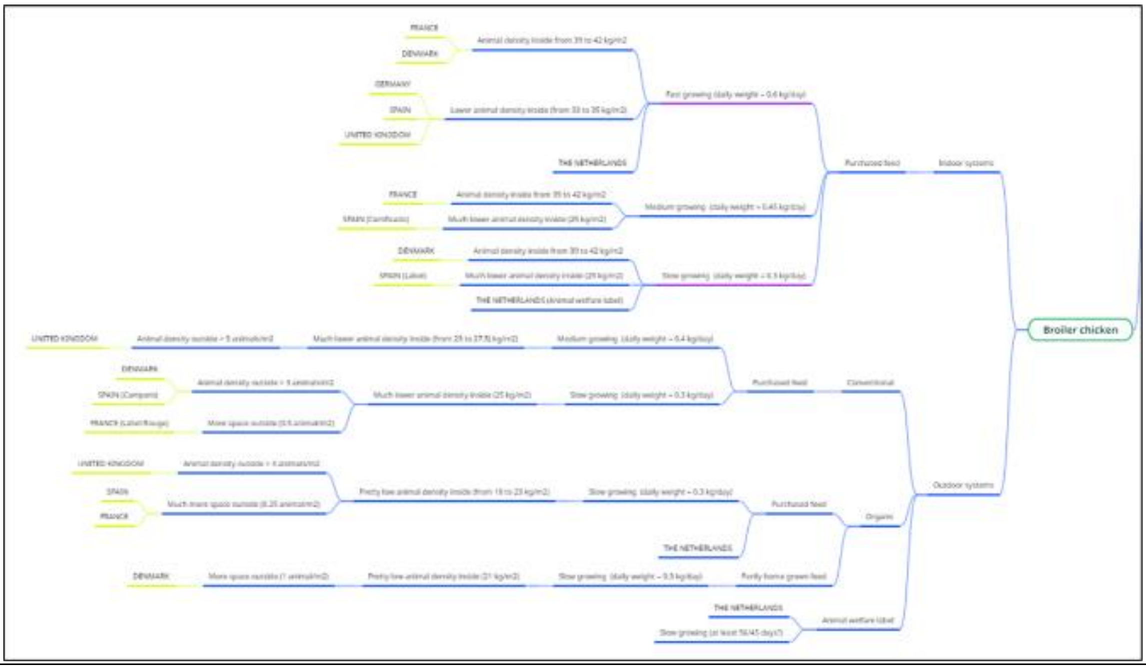
Due to the common data between poultry sectors a formal data merge was not undertaken.

From the expert survey, 18 broiler systems were defined according to the type of housing, intensity of production, the type of production (conventional, organic), the quantity of concentrates and the presence of outdoor production. The broiler systems included many indoor systems designed for fast growing breeds and maximum efficiency (up to eight cycles per year). However, free-range indoor or extensive outdoor systems also exist in many countries, e.g. Label Rouge in France, Denmark, Spain and UK, though all were noted as "niche" or less common. The indoor intensive systems achieve growth rates of around >60g/day, whilst the extensive systems may only achieve half of that. Concentrate use was also quite varied, ranging from 3 kg to almost 16kg per bird, whilst the number of birds per cycle varied from around 5000 up to 60,000 in some countries.

For the synthesis all the data sources were examined and manually matched for the key parameters, including stocking density, location and socio-economic factors. This process was only able to identify two main broiler system clusters.

Eurostat	FADN technical	FADN Economic
		

Tree of systems (survey)



Broiler synthesis

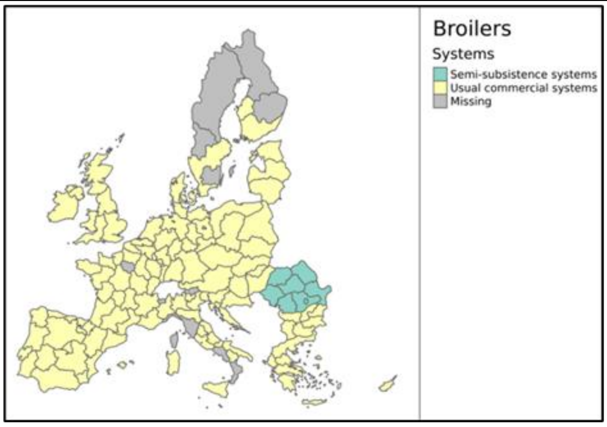


Figure 21 Broiler systems in European, defined through databases and expert analysis.

Appendix 2 Expert survey

Please see a copy of the email sent to 116 recipients asking for input regarding the initial characterisation of European livestock systems (sent 08/06/2022) and containing the subsequent survey file (see next page).

Cc: elea.bailly@fibl.org

T3.1_Characterisation.xlsx
260 KB

FADN_livestock_farm_types.xlsx
263 KB

2 attachments (523 KB) Save all to OneDrive - Aberystwyth University Save All Attachments

Dear partners,
At the Uppsala meeting, Task 3.1 was presented by Eléa and we now need your help to characterise the livestock systems of Europe. Apologies if you received this email in error or are not able to contribute to livestock characterisation, but we hope academic, practise hub and multiactor stakeholders are able to contribute their knowledge to this task, even if it's only for one system or sector.

This email is a first step to identify the existing systems, including mainstream conventional and organic, but also existing niche systems. This first data collection will form the basis of a more detailed system description that will be developed in the autumn.

There are two files attached to this email:

- A Task 3.1 characterisation questionnaire file
- FADN livestock farm types database

For the questionnaire file we ask you to enter the livestock systems in your country. It is split into different sheets for varying types of species or systems. Feel free to enter data for different species. For mixed systems please enter data for both livestock species in the respective sheets and indicate that they are linked via their system name or a number.
Hopefully most of the questions are self-explanatory, but if you prefer to provide this information via an interview, then please contact Eléa (email in cc) to arrange an appointment. All information entered can be estimates, but you may wish to check some national statistics or management handbooks etc for e.g. yield or feeding data etc. It is also possible to send us documents about your national systems and we can help by entering the data. As most institutions (and countries) have more than one contact person, maybe some internal organisation is required to avoid people duplicating efforts.

The second file presents FADN database results, split by country and farm types. These are average values for that country and farm type and may be interesting or help inform your system descriptions. What we expect is that within each row of average data, there are two or more sub-systems, and this is what we hope to obtain from the questionnaires.

Apologies for requesting your time for this task, but we really need your local expertise to identify the existing livestock systems, and especially the detail, such as replacement rates, feeding, access to grazing etc. We would be very grateful if all files could be sent to us by Friday July 1st at the latest.

Many thanks in advance
Simon and Eléa

sim44@aber.ac.uk
elea.bailly@fibl.org

Pathways FOR SUSTAINABLE FOOD

Pathways FOR SUSTAINABLE FOOD

Table 15 Extract of baseline system expert survey questions (dairy sector as an example)

Please enter typical values and a full text description of dairy systems within your country					
			input type	Example	System 1
Farm system	Country		*dropdown*	*United Kingdom*	
	Production species type		*dropdown*	*dairy cows*	
	Lowland or Less favoured area		*dropdown*	Lowland	
	Production method		*dropdown*	Conventional	
	Representativeness of the system for production type	Is the system common or a niche?	*dropdown*	Fairly common 25-50% of animals	
	Farm type (General_TF)		*dropdown*	Specialist_grazing_livestock	
	Specific type (TF_SUBP4)		*dropdown*	Specialist dairying	
	Other livestock on the farm_1		*dropdown*	no	
	Other livestock on the farm_2		*dropdown*	no	
	Text description of the system	E.g. intensive/extensive, traditional/new, main feeds, any specific characteristics, collaborations, family or paid labour etc	*free text*	semi-intensive grazing dairy system. Swards of PRG with high N input.	
	Please describe the location(s) and production environment of the system	E.g. geographical location, is it in the lowlands, or an upland area, a particular region, does it use forests or rough grazing etc	*free text*	Typically in Southern and Central England, lowland grassland farms with productive grasslands and some maize area.	
Sustainability	Perceived sustainability of this system in terms of economics, environmental and social issues	E.g. economics (e.g. viability), environmental (e.g. GHGs) or social (e.g. labour) positives/negatives	*free text*	Economics can be difficult, with increasing herd size and poor labour supply issues	
Animal welfare	Animal welfare positives and negatives of this system	Space, natural behaviour, impact of health and longevity, weaning strategy (milk replacer, real milk, cow-calf,	*free text*	Grazing system but welfare can be problematic with feet and fertility issues, 30%+ replacement rate	

Biodiversity	Biodiversity positives and negatives of this system	Direct and indirect impacts of the system of biodiversity locally (e.g. hedges, ponds...) and globally (e.g. use of SA soya)	*free text*	Land has low biodiversity due to high N inputs and reseeding. Some hedges and small natures areas. Uses some soya of unknown origin	
Land use	Typical farm size		*ha*	120	
	Permanent grass		*%*	20%	
	Temporary grass/legumes		*%*	50%	
	Maize (forage)		*%*	30%	
	Cereals, oilseeds, pulses		*%*	0%	
	Roots/tubers		*%*	0%	
	Nature/environmental areas		*%*	0%	
	Other		*%*	0%	
			Sum check	*Ok*	*Ok*
Land management	Forage/crop species diversity		*number*	Low	
	Land use intensity		*N kg/ha/year*	250	
	Use of external fertilisers		*dropdown*	Med level NPK	
	Use of pesticides		*dropdown*	Low	
Livestock production	Milk sold for		*dropdown*	Liquid milk	
	Main breed type		*dropdown*	High yielding dairy e.g. HF	
	Cows per farm		*head*	200	
	Milk yield per cow		*kg/cow/annum*	8000	
	Productive lifespan		*lactations/cow*	3	
	1st calving age		*months*	26	
	Replacements		*dropdown*	Reared on farm	
	Other calves sold?		*dropdown*	Sold <14days	
	Mutilation	E.g. castration, tail docking, de-horning etc?	*dropdown*	Multiple with anaesthesia	
Grazing	Grazing days		*days/year*	210	
	Access to shared/common grazing lands, e.g mountains, moors, forests?		*dropdown*	no	
	If "yes", how much		*animal * grazing days/year*		
Forages	Summer	Summer period	*months*	7	
		Main forage	*dropdown*	Grazed grass	
		Secondary forage	*dropdown*	None	
	Winter	Winter period	*months*	5	
		Main forage	*dropdown*	Maize silage	
		Secondary forage	*dropdown*	Grass silage	
	Purchased forage/bulk feeds		*dropdown*	<10% of total forage	
	Type of purchased forage/bulk feed		*dropdown*	Brewing/Distillers grains	
Concentrate feeds	Concentrate feeds	Quantity	*kg/cow/year*	1800	
		Protein %	*CP%*	22%	
	Human edible feed in concentrates		*%*	50%	
	Concentrates grown on farm	Proportion of total	*%*	0%	
Housing	Housing type		*dropdown*	Steel frame - Cubicles	

	Animal density in housing		*m2/animal*	8.00	
	Milking system		*dropdown*	Large >32 e.g. rotary	
Manu re	Manure system			Slurry-natural crust	
	Manure exported off-farm	Exported %	*%*	0%	