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Applying life cycle assessment to European high nature value farming systems: Environmental impacts and biodiversity

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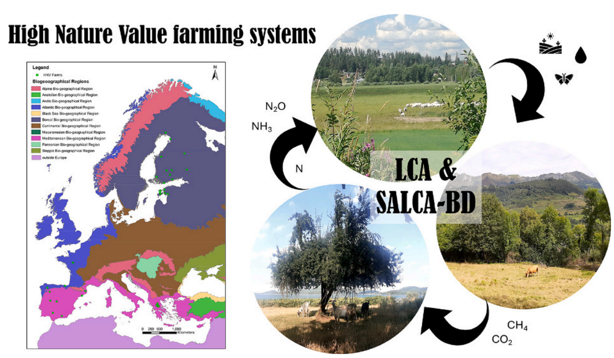
HIGHLIGHTS

- Sheep production systems showed the highest global warming potential impact within HNV farms.
- Goat production systems showed the highest land use values withing HNV farms.
- Greek farms showed high environmental impacts due to low production volumes.
- Highest biodiversity values occurred on farms based on only semi-natural grasslands.
- HNV farms showed low GWP_{100} values per kg of beef and cow milk.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Life Cycle Assessment (LCA) remains a method of choice for assessing the environmental performance of agricultural systems. However, it is rarely applied to multifunctional extensive production systems, in which livestock use, apart from animal production, maintains a continuous disturbance that sustains the diversity of habitats and species.

OBJECTIVE: This study aims to assess the environmental impact and biodiversity of extensive ruminant production on semi-natural grasslands (SNG), that is, High Nature Value (HNV) farming across Europe. We collected data from a total of 41 HNV farms in five countries (Finland, Estonia, Spain, Greece, and France) that produce beef, sheep, and goats, and that incorporate (to a varied degree) semi-natural and permanent pastures into production.

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Semi-natural habitats
Ruminant production

METHODS: We used LCA to assess the potential environmental impact of HNV farms according to global warming potential (GWP_{100}), fossil resource scarcity (FRS), water scarcity (WS) and land use (LU), by using the Solagro Carbon Calculator and OpenLCA software. We assessed biodiversity based on the expert scoring system of SALCA-BD. We compared impacts on per area and per product basis across the farms, and related them to the productivity.
RESULTS AND CONCLUSIONS: Results revealed a considerable variation in all environmental impacts among HNV farms, explained mostly by the type of ruminants, main product (meat or milk) and the production level. GWP_{100} per unit in beef product in France was almost twice as high as that in boreal and 3 times more than in Spain, while sheep systems in Greece varied 7-fold for meat. Sheep systems consistently had the highest GWP_{100}, while goat systems used the most land, fossil fuel and water. Small ruminant production in Spain had both the highest land occupation and biodiversity values. Biodiversity was at its highest on farms utilising only SNG for production, which, however, related negatively to the farms' production output. Enteric fermentation accounted for 32% of overall emissions.
SIGNIFICANCE: This study makes a novel contribution towards a better understanding of the environmental performance and production capacity of HNV farming systems that are often used as examples of multifunctional and sustainable ruminant-based production.

1. Introduction

Livestock production systems vary greatly along the gradient of production intensity, which influences the environmental impact of animal-based food production (Poore and Nemecek, 2018). LCA studies remain the method of choice for comparing environmental impacts of agriculture, including livestock production (FAO, LEAP, 2020). The most common approach is to evaluate the environmental impacts based on the amount of product output (Alig et al., 2012). Intensive livestock production, which maximises animal and farm productivity in terms of outputs of meat or milk outputs, has shown higher resource use efficiency and lower greenhouse gas emissions per kg of product compared with extensive production (Ripoll-Bosch et al., 2013). On the other hand, extensive production, especially of ruminants in pastoral systems, is known to also provide other ecosystem services and maintain biodiversity on farmland (Garnett, 2010; Ripoll-Bosch et al., 2013; Thompson et al., 2023), although such services are barely quantified and often overlooked (Dumont et al., 2019). High levels of biodiversity and multifunctionality in livestock systems are typically compromised by increasing farm productivity (Gabriel et al., 2013). While multifunctionality and ecosystem services related to production are challenging to capture in LCA (Crenna et al., 2019; Zira et al., 2023), there is considerable potential for developing LCA methods to better capture such additional outputs (Bragaglio et al., 2020; von Greyerz et al., 2023; Kyttä et al., 2023).

When livestock production sustainability discourse focuses mainly on GWP_{100} and product-level assessment, there is a high risk of depreciating alternative mitigation opportunities to intensify production (Manzano et al., 2023). An alternative pathway is to mainstream multifunctional pastoral livestock systems by improving their socio-economic viability and integrated development (Lomba et al., 2019). In Europe, such production is known as HNV farming systems – the term that encompasses traditional farmland production 'where agriculture is a major land use and where that agriculture supports, or is associated with, either a high species and habitat diversity or the presence of species of European conservation concern or both' (Andersen et al., 2003). HNV farmland may cover as much as 30% of agricultural land at the European Union (EU-27) level (European Commission, 2014). Although specific production practices vary by region, the majority of HNV farming systems are characterised by long-established, predominantly low-intensity, and often complex production, such as traditional agroforestry, orchards, small-scale mixed livestock and polycrop systems, as well as extensive pastoral ruminant production (examples in Lomba et al., 2019). Producers commonly utilise areas of unimproved grassland (semi-natural vegetation) for grazing or hay production, sometimes on common land, applying low to zero amounts of mineral fertilizers and pesticides; in some regions, they also use labour-intensive practices and keep traditional livestock breeds and crop varieties adapted to local conditions (Paracchini et al., 2008). HNV farming systems have been used as prime examples of biodiversity-rich and nature-friendly agriculture in Europe (Lomba et al., 2023). Beyond food production, they provide a wide range of ecosystem services (e.g. prevention of soil erosion and fire risk, water retention, preservation of genetic agrobiodiversity, and maintaining scenic cultural landscapes) (Plieninger et al., 2019), contributing to the socio-economic viability of rural communities (Lomba et al., 2019). Recently, HNV farmlands have been identified as significant reserves of soil organic carbon (Gardi et al., 2016). For this reason, the HNV farmland indicator was used in the EU sustainability indicator framework (Andersen et al., 2003), although it was later discontinued because of practical difficulties in quantifying it and monitoring.

Thus far, HNV farming systems have received only minor research attention in environmental assessments of food systems, including LCA. For example, among 500 datasets representing about 38,700 commercially viable farms in 119 countries and 40 products reviewed in Poore and Nemecek (2018), only three datasets are from ruminant systems corresponding to HNV farming in Europe. This restricts a full appreciation of the potential and limitations of HNV farming systems in transitioning to sustainable food systems and their production capacity to meet the demand for animal-based food. This study aims to fill this gap by assessing the environmental performance of HNV farming systems across European regions through LCA that includes biodiversity. The specific objectives are to: i) assess the environmental impact in terms of GWP_{100}, FRS, WS and LU of HNV farms, ii) complement the assessment with biodiversity valuation of farms, and iii) explore the biodiversity values along the gradient of productivity and among types of production of HNV farms.

2. Material and methods

2.1. Study sites

We established a collaborative network spanning Greece, Spain, France, Estonia and Finland for data collection. The network comprised key stakeholders such as farmers, researchers and organizations directly engaged with farmers. The main criterion for the farms to enrol in the study was the inclusion of SNG in production as the main source of forage for ruminants, aligning with the definition of HNV farming systems. Equine farms were excluded, and only farms with typical ruminant production for each region were considered. Suitable farmers were directly contacted by national expert researchers, except in Finland, where we issued an open call through social media. Given the substantial variation in operational HNV farming systems, our aim was not to obtain a representative sample but rather to capture the diversity.

A total of 41 farms were enrolled in the study, consisting of: 22 beef cattle, 4 sheep, 2 goat, 5 sheep–goat, 3 dairy and 5 combined beef–sheep–goat farms (Table 1). The farms were located across key bioregions in Europe, except the continental region (Appendix A). Farmers completed a questionnaire providing primary data on their farming practices and farm structure. We collaborated with national experts in each region to translate and adapt the questionnaire, ensuring clarity and ease of understanding for participating farmers. National coordinators assisted farmers in their respective regions and subsequently addressed any inconsistencies in the data provided through follow-up calls to minimize bias.

2.2. Environmental impact

We assessed the potential environmental impact of HNV farms through attributional LCA using two types of software: the Solagro CC (Tuomisto et al., 2015) and OpenLCA 1.11. The CC tool, tailored to cover EU-27 specifications such as climate, follows international LCA standards (for further details in the methodology, see Tuomisto et al., 2015 and Bouwman et al., 2002). The system boundary applied in this study was from cradle to farm gate. We applied the ReCiPe Midpoint 2016 (H) impact method to estimate GWP_{100} (kg carbon dioxide (CO_2) eq), FRS (kg oil eq) and LU (m^2a crop eq) and the AWARE method to assess regionalised WS (m^3). The functional units used in the LCA were one hectare (ha^{-1}) and yield, expressed in kg of product for milk (kg ECM $milk^{-1}$) and meat live weight (kg LW^{-1}). Environmental impact values per product were calculated by dividing impacts per ha by the total yield of animal products (kg LW and kg ECM milk) per ha for each HNV farm. We applied a biophysical allocation method between milk and meat in mixed production systems following Product Environmental Footprint (PEF) guidance (PEF Guidelines, 2021). Fat and protein content values reported by farmers in the questionnaires were used to estimate the fat- and protein-corrected milk.

Our assessment of the environmental impact was based on a yearly production cycle estimated from 5-year average data reported by farmers. The life cycle inventory was based on data collected in the questionnaires, ad hoc calculations and results from the CC. We included diesel usage in agricultural production (MJ), water consumption (l), land occupation per type of land (ha), mineral fertiliers, feed and plastic purchases based on data collected from the farms. The emissions flows included in the analysis were ammonia (NH_3), dinitrogen monoxide (N_2O), methane (CH_4) from enteric fermentation and other greenhouse gas emissions (CO_2) relevant to manure management, mineral fertilizers, feed and plastic purchases. We used the CC to assess greenhouse gas emissions (CH_4, CO_2 and N_2O), total nitrogen (N) inputs and outputs (N kg/ha) at the farm gate and the contribution of certain farming practices, such as manure management or feed purchases, to the overall GWP_{100} for each HNV farm. The emissions resulting from the use of peat as bedding material in 5 out of 41 Finnish and Estonian farms were assessed by using an emission factor of 860 kg CO_2 eq m^{-3} and density of 200 kg m^{-3} (Manninen et al., 2016). We excluded capital goods from the analysis because of minimal machinery and building sizes in HNV farming systems.

2.3. Assumptions

We used the best available estimates from a variety of national statistics databases for agricultural yield values. Averaged yields of the main feed crops, such as triticale, alfalfa, barley, faba beans and oat, were determined based on the country-specific production average yields of the last 4 years in respective regions (Agreste, 2020; Institute of Natural Resources Finland, 2021; Oras et al., 2020; Ministry of Agriculture and Fisheries Spain, 2021; Ministry of Agriculture Greece, 2021). We considered yields of 1.8 t DM ha^{-1} (DM, dry matter) for SNG in Finland (Saastamoinen et al., 2017), 2 t DM ha^{-1} in Estonia (Oras et al., 2020), 2.2 t DM ha^{-1} in Greece (Skapetas et al., 2004) and 3 t DM ha^{-1} in France and Spain (Agreste, 2020; Universidad de Córdoba, 2024). SNG in production was included in the total utilised agricultural area (UAA) of each farm as pastures and other field crops. To avoid double counting in the UAA, cover crops were included as a percentage of legumes, with corresponding yields adapted for the field. We assumed 21% of legumes in SNG in Finland and Estonia (Riesinger and Herzon, 2008), 24% in Spain and Greece (Olea et al., 1990) and 22% in France (Agreste, 2020). For cultivated pastures, we assumed 34% in Finland and Estonia (Riesinger and Herzon, 2008) and 36% in Spain (Olea et al., 1990).

We relied on farmer-reported dietary composition referred to protein feed purchases and other feed intake. We also included estimated forage intake during grazing. For this, we applied the same methodology as in Torres-Miralles et al. (2022) to estimate forage intake originated from SNG and other pastures. We assumed that all crop production was for feed purposes, with no residues left in the field. Calculations were based on specific live weights, ages, growth rates and energy requirements per animal category, breed and metabolizable energy (ME) concentration of low-quality forage. The ME concentrations applied for SNG were 8 MJ kg^{-1} DM in Finland, 10 MJ kg^{-1} DM in Estonia (Institute of Natural Resources Finland, 2021), 10.2 MJ kg^{-1} DM in Spain and Greece (Universidad de Córdoba, 2021) and 10.56 MJ kg^{-1} DM in France (Rodrigues et al., 2007). For other pastures, the ME concentrations were 11.3 MJ kg^{-1} DM in Finland, 10.8 MJ kg^{-1} DM in Estonia (Natural Resources Institute Finland, 2021), 11.3 MJ kg^{-1} DM in Greece, 11 MJ kg^{-1} DM in Spain (Universidad de Córdoba, 2021) and 11.5 MJ kg^{-1} DM in France (INRAE, 2022).

The energy requirements of cows, calves, growing bulls, and heifers were estimated according to Finnish nutrition requirements (Natural Resources Institute Finland, 2021) (see Torres-Miralles et al., 2022 for additional details). Energy requirements for sheep and goats varied by stage – pregnancy, suckling and maintenance. The nutritional requirements per stage were based on Finnish requirements for sheep (Natural Resources Institute Finland, 2021). For the maintenance stage of goats, an average for free-ranging goat studies was applied (Lachica et al., 1999; Lachica et al., 1997; Lachica and Aguilera, 2003).

We estimated growth rates based on live weight breed characteristics and age data provided by farmers in the questionnaire for growing bulls, heifers, calves and lambs. In cases of missing data, we estimated values from relevant literature (e.g. Huuskonen et al., 2017 for Finnish cattle) and used the questionnaire averages for the respective region and production type. We assumed no growth for suckler cows, adult bulls, ewes and rams. Dressing percentages considered in this study were based on average values from slaughter data from the Finnish Food Authority (Natural Resources Institute Finland, 2021) from a minimum of 44% for dairy cows to a maximum of 55.9% for a bull >2 years for the beef breed (see Table 8.2 in the repository). To ensure data accuracy, particularly given the major influence of certain parameters (i.e. herd size) on final environmental impact results, we compared production volumes resulting from our calculations with those estimated in the CC (with the functional unit being 1 kg of product).

2.4. Biodiversity values

We estimated the potential biodiversity impact of the farms by using the expert scoring system SALCA-BD (Jeanneret et al., 2014; Lüscher et al., 2017). The SALCA-BD scores represent both adverse and beneficial land occupation impacts of agricultural production on terrestrial species diversity at the field scale. The terrestrial species assessed in SALCA-BD (defined as indicator species groups) include grassland flora, birds, small mammals, amphibians, molluscs, spiders, carabid beetles, butterflies, wild bees, and hoppers. For each indicator group, the score results from a rating R ($1 < R < 5$) of the impact of the management option (1, highly damaging to 5, favourable) multiplied by the mean value C ($1 < C < 10$) of two weighting coefficients. The coefficient C takes into account the habitat suitability and the relative importance of farming activities (e.g. grazing vs mowing) for the given indicator group in which the management option occurs (see Jeanneret et al., 2008 for

Table 1
Main characteristics of the study region, farm structure, herd structure and inputs of High Nature Value farms in Finland, Estonia, Spain, Greece and France (means ± *SD*).

Biogeographical region	Boreal		Mediterranean		Atlantic
Region	Finland	Estonia	Greece	Spain	France
Mean annual temperature	4.3 °C	6.8 °C	13.9 °C	13.5 °C	12.5 °C
Mean annual precipitation	579 mm	639 mm	642 mm	731 mm	663 mm
Vegetation	Cultivated grassland and cropland: barley, oats, silage, hay	Cultivated grassland and cropland: barley, oats, hay	Highland, mid-valley grassland, shrubland and forest pastures	Alpine pastures, highland, mid-valley grassland, shrubland and open forest pastures	Mid-valley grassland, permanent pastures
Typical semi-natural habitat	Coastal and forest pastures	Coastal and forest pastures	Grassland, forest pasture	Grassland, forest pasture	Grassland
Type of production	Beef, sheep, mixed production (beef and sheep)	Beef and dairy	Mixed production (sheep and goat), beef	Sheep, goat, beef, dairy, mixed production (sheep and goat)	Beef and dairy
Number of farms	11	8	8	9	5
Farm structure					
Total on-farm land use (ha)	274 (± 232)	451 (± 414)	30 (± 19)	935 (± 1908)	146 (± 42)
Arable crop land (ha)	22 (± 36)	33 (± 63)	2 (± 4)	0 (± 0)	19 (± 21)
Arable forage land (ha)	113 (± 119)	67 (± 85)	2 (± 4)	1 (± 3)	22 (± 11)
Semi-natural grassland combined (ha)	138 (± 128)	351 (± 349)	26 (± 19)	934 (± 1910)	105 (± 34)
Communal off-farm land (yes/no)	no	no	yes	yes	no
Surface of herbaceous forage (% of total)	93% (± 11)	94% (± 9)	95% (± 9)	100% (± 0)	88% (± 1)
Feed autonomy	90% (± 24)	90% (± 26)	46% (± 32)	83% (± 14)	85% (± 31)
Purchased feed	Rapeseed, protein crops	Silage, maize, barley	Hay, pea, alfalfa, roughage, straw, maize, barley, soy	Hay, protein crops, silage, straw	Protein crops (cereals), alfalfa, maize
Herd details					
Breeds	Eastern Finncattle, Aberdeen Angus, Ayrshire, Holstein, Highland cattle, Charolais, Simmental	Simmental, Hereford, Limousin, Aberdeen Angus	Karagounis-Chiotiko, Greek Red	Charolais, Frisona	Montbéliarde, Charolais, Limousin
Herd size	172 (± 195)	204 (± 232)	27 (± 29)	83 (± 91)	202 (± 145)
Suckler cows	66 (± 75)	62 (± 59)	10 (± 14)	34 (± 32)	78 (± 51)
Milking cows	–	11 (± 32)	–	16 (± 33)	10 (± 22)
Heifers	30 (± 35)	50 (± 55)	7 (± 6)	7 (± 7)	42 (± 26)
Steers	26 (± 36)	27 (± 34)	–	–	38 (± 20)
Calves	43 (± 45)	52 (± 52)	9 (± 8)	24 (± 18)	30 (± 24)
Bulls	8 (± 5)	2 (± 2)	1 (± 1)	3 (± 2)	4 (± 1)
Breeds	Finnsheep	–	Cross-bred	Castilian sheep, Segurena, Ripollesa, cross-bred	–
Herd size	248 (± 203)	–	265 (± 206)	761 (± 758)	–
Ewes	96 (± 76)	–	132 (± 97)	383 (± 393)	–
Non-reproductive ewes	4 (± 9)	–	–	32 (± 41)	–
Rams	3 (± 4)	–	6 (± 4)	9 (± 8)	–
Lambs	145 (± 115)	–	127 (± 105)	337 (± 317)	–
Breeds	–	–	Skopelou	White goats, cross-bred	–
Herd size	–	–	155 (± 151)	193 (± 110)	–
Goats	–	–	69 (± 65)	98 (± 49)	–
Female goats	–	–	3 (± 6)	16 (± 9)	–
Billy goats	–	–	4 (± 3)	8 (± 8)	–
Goat kids	–	–	80 (± 77)	71 (± 43)	–
Reproductive management					
Cattle sold per year	56 (± 92)	72 (± 99)	6 (± 6)	22 (± 27)	68 (± 54)
Sheep and goats sold per year	141 (± 112)	–	157 (± 146)	398 (± 388)	–
Grazing time (% time spent annually) – ruminants*	35% (± 9)	31% (± 14)	71% (± 21)	76% (± 20)	51% (± 19)
Grazing time (% time spent annually) – small ruminants*	47% (± 19)	–	77% (± 25)	70% (± 19)	–
* Potentially available grazing period in each country is limited by the availability of pasture fodder					
Beef live weight of sold animals (t)	28 (± 37)	30 (± 31)	4 (± 3)	8 (± 6)	42 (± 27)
Lamb / goat live weight of sold animals (t)	5 (± 4)	–	3 (± 3)	5 (± 5)	–
Cow milk (t)	–	508 (± 0)	–	250 (± 0)	155 (± 0)
Sheep milk (t)	–	–	24 (± 26)	–	–

(*continued on next page*)

Table 1 (*continued*)

Biogeographical region	Boreal		Mediterranean		Atlantic
Region	Finland	Estonia	Greece	Spain	France
Goat milk (t)	–	–	6 (± 6)	4.8 (± 0)	–
INPUTS					
Energy use					
Diesel used (l)	7873 (± 9907)	17,010 (± 19,024)	1545 (± 1039)	1403 (± 1397)	9525 (± 5900)
Fertilizers					
Inorganic fertilizers (number of farms where used)	1 out of 11	1 out of 8	none	none	2 out of 5
Nitrogen (kg/ha)	240 (± 0)	–	–	–	250 (± 141)
Phosphorous (kg/ha)	–	–	–	–	200 (± 0)
Organic nitrogen / manure (Nitrogen, kg/ha)	6 (± 10)	3 (± 8)	1 (± 2)	0 (± 0)	1 (± 2)
Pesticides					
Pesticides (number of farms where used)	none	none	1 out of 13	none	1 out of 5
Number of treatments	none	none	1	none	1

more detail). Aggregated at farm level, a higher farm score indicates less impact on biodiversity, meaning that the farm has suitable and important fields in terms of habitats for several indicator species groups and uses practices that favour their occurrence (Jeanneret et al., 2014). Information on the farming practices applied per country and field type in this study was obtained from questionnaires. We related these practices to the respective practices included in the SALCA-BD method (see example for unproductive grassland type in Appendix B).

The major field types from SALCA-BD present in the studied HNV farms were fallow, leys (artificial meadows), winter cereals, grain legumes, grassland type I (unproductive), grassland type II (moderately productive) and forest pastures (Table 2). We matched these with the best-matching field types in our dataset: SNG (combination of forest pastures and grassland type I (unproductive) for Greece and Spain, grassland type I (unproductive) for Finland, Estonia and France), permanent grassland (grassland type II – moderately productive), cultivated grassland (leys – artificial meadows), cereal crops such as oats, barley and maize (winter cereals), and legumes and protein crops such as faba beans and peas (grain legumes) for all the countries. The variation among the scores for the same field type in different countries arises from the varying management practices typical of the farms in those countries (e.g. mowing frequency) based on the collected questionnaires.

2.5. Biodiversity of farm systems and productivity

The productivity of farms differs considerably depending on whether the same livestock are utilised for dairy or meat production (Poore and Nemecek, 2018). To investigate the biodiversity values of farms across the productivity gradient within our dataset, we expressed farm productivity as yields of either meat (kg LW ha^{-1}) or milk (kg/ha) derived from all the farm's livestock combined relative to its total agricultural area. For farms with combined meat and milk production, we examined

Table 2
SALCA-BD scores per field type and country.

Production system	Finland	Estonia	France	Greece	Spain
Fallow	15.1	15.1	15.1	15.1	15.1
Grain legumes	5.8	5.6	5.6	5.6	5.8
Leys (artificial meadows)	4.6	5.1	5	4.6	5
Winter cereals	7.2	6.8	7.2	7.2	7.2
Grassland type I (unproductive)	19.5	19.6	19	19.4	19.4
Grassland type II (moderately productive)		11.8	11.8		
Forest pastures				20.4	20.4

productivity as either meat or milk yield per area within the corresponding data subset. We ran correlation analysis for farms with meat production but not those with milk production because of a particularly small size of the latter's subset. We used one-tailed significance testing based on an expected negative relationship between productivity and biodiversity. We further examined characteristics of the farms with exceptionally high productivity values.

3. Results

3.1. SALCA-BD scores of High Nature Value farms

We calculated a final biodiversity score per HNV farm (Table 2) by aggregating the calculated SALCA-BD score of each field type for the farm's whole LU profile – that is, the combination of different field types on the farm – and dividing the final score by the total area of the farm (see example in Appendix C).

In this study, the final biodiversity score per ha per HNV farm was used as the biodiversity variable. Such a variable expressed a positive impact, contrary to the rest of the environmental impacts.

3.2. Environmental impact and biodiversity of High Nature Value farms

The results based on 41 HNV farms across five countries showed a wide variation in environmental impact and biodiversity, both among and within countries (see Database: https://doi.org/10.6084/m9.figshare.24942348) (Fig. 1). Depending on the specific impact categories, farms from different countries demonstrated varying performance levels (Appendix D). Farms located in the boreal region (Finland and Estonia) and in Spain had the lowest GWP_{100} per ha compared with other countries, with overall variation remaining within a range of 5 times. Several sheep–goat production farms in Greece and Spain showed exceptionally high GWP_{100} for their respective countries. In terms of LU, most farms fell within a range of 4000–6000 m^2a crop eq ha^{-1}, with only 2 farms (one in Finland and one in Greece) having values below this range. The variation in FRS impact was high for Spain and Greece, with 2 farms with particularly high values (up to 80 kg oil eq ha^{-1}). FRS impact corresponds to the cost of extracting fossil fuels for fuel use. Therefore, a lower amount of fuel in use shows high FRS impact values, which is consistent with the study results. Spanish farms also had the highest WS values. N balances were predominantly negative across HNV farms in all countries. Finally, biodiversity values were on average highest on Spanish and Greek farms, while Finnish farms showed the lowest average values, although the range of variation remained within 100%.

The variation in impacts per kg of product was even more

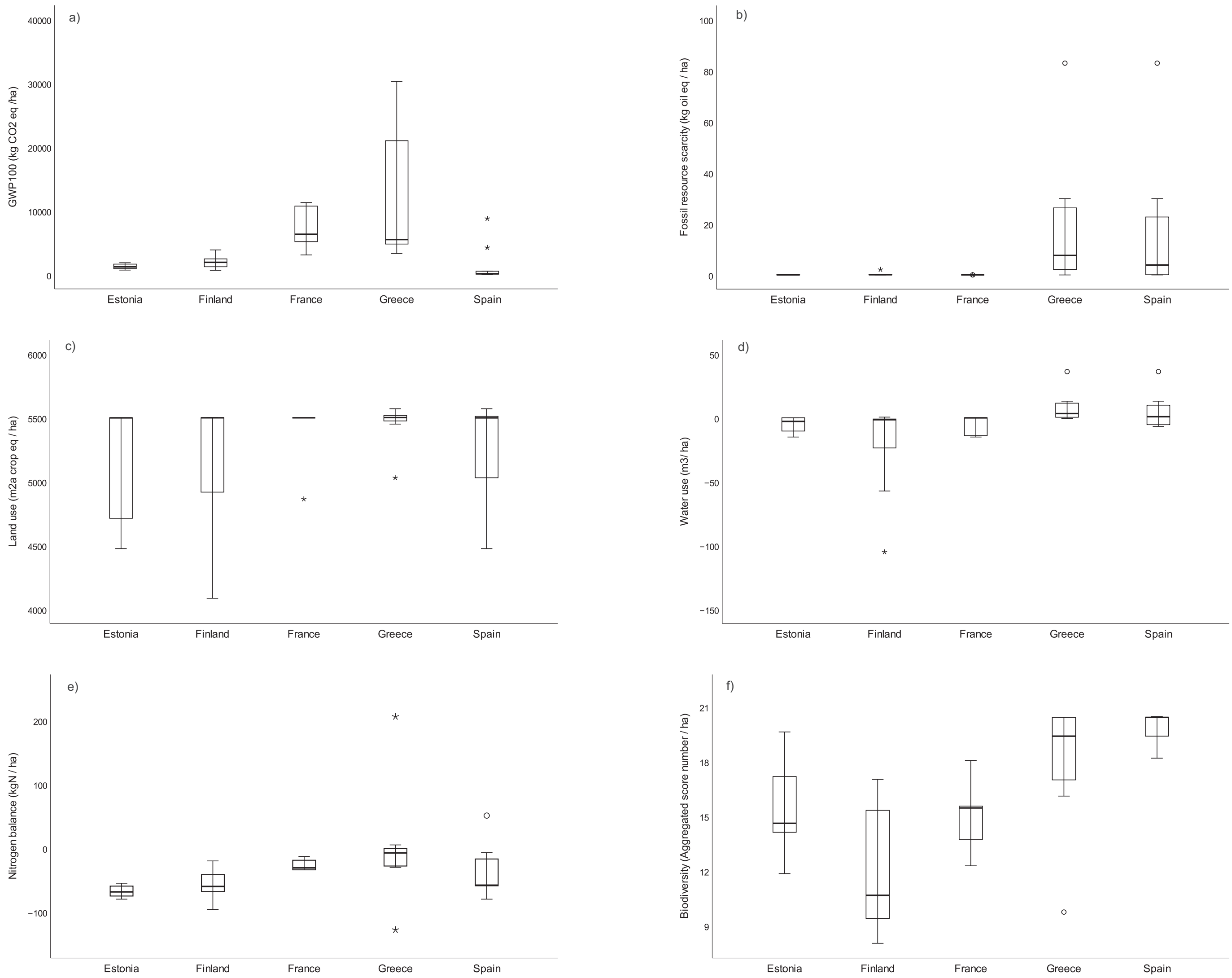

Fig. 1. Average, quartile, standard error bars and outlier values for 41 High Nature Value farms for six environmental indicators per hectare in five countries: a) global warming potential (GWP_{100}) (kg CO_2 eq), b) fossil resource scarcity (FRS) (kg oil eq), c) land use (LU) (m^2a crop eq), d) water scarcity (WS) (m^3), e) nitrogen (N) balance (kgN) and f) biodiversity.

Table 3
Aggregated average values for four environmental impact categories: global warming potential (GWP_{100}) (kg CO_2 eq), fossil resource scarcity (FRS) (kg oil eq), land use (LU) (m^2a crop eq) and water scarcity (WS) (m^3) per country, in kg live weight for beef and sheep meat and kg ECM milk for bovine and sheep goat milk.

Bioregion	Country	Product	GWP_{100} (kg CO_2 eq kg^{-1})	LU (m^2a crop eq kg^{-1})	FRS (kg oil eq kg^{-1})	WS (m^3 kg^{-1})
Boreal	Finland	Beef (meat)	28	87.5	7.7E-04	−2.6E-02
		Sheep (meat)	57.3	237.6	1.5E-03	−5.0E-02
	Estonia	Beef (meat)	22.0	92.9	1.1E-03	−7.6E-02
		Bovine (milk)	1.8	4.2	7.4E-05	−6.4E-03
Mediterranean	Greece	Beef (meat)	80.8	44.4	9.5E-04	−2.0E-02
		Sheep–goat (meat)	40.5	54.3	7.0E-04	−1.5E-02
		Sheep–goat (milk)	3.6	3.8	4.7E-05	−7.7E-04
	Spain	Beef (meat)	14.0	226.2	1.7E-01	7.6E-02
		Sheep–goat (meat)	20.7	1489.5	4.9E-01	7.1E-02
		Sheep–goat (milk)	6.8	416.2	1.5E-02	6.6E-02
		Dairy (cow milk)	2.1	1.3	1.9E-02	8.5E-03
Atlantic	France	Beef	22.0	22.2	4.6E-04	−1.6E-01
		Dairy (cow milk)	1.6	9.3	2.5E-04	−7.4E-02
All		Beef (meat)	35.0	94.9	2.5E-02	−4.9E-02
		Sheep–goat (meat)	36.0	919.8	2.8E-01	2.3E-02
		Cow (milk)	1.8	5.0	6.6E-03	−2.4E-02
		Sheep–goat (milk)	3.6	3.8	4.7E-05	−7.7E-03

pronounced than for impacts per ha (Table 3). There were also considerable differences between the production systems. Sheep systems consistently had the highest GWP_{100} per product, followed by goat, beef and dairy. Goat-based production used most land per product (over 20 times that of beef) and had the highest FRS and WS, followed by sheep, beef and dairy. HNV beef and small ruminant production had average levels of GWP_{100} of 40.1 and 51.8 kg CO_2 eq kg LW^{-1} for meat products, respectively, while HNV cow milk and small ruminant milk had levels of 2.6 and 11.5 kg CO_2 eq kg ECM $milk^{-1}$, respectively.

The LCA results demonstrated that enteric fermentation contributed most to the average overall emissions (32%), followed by mineral fertilization (20%), animals purchased (10%), feed purchased (10%), indirect emissions (8%) and direct N_2O emissions (7%) (Fig. 2).

3.3. Productivity and biodiversity

Productivity per ha of UAA, including semi-natural habitats, reached 300 kg LW on 5 farms (13% of the farms with meat production), all producing beef, and 1 t milk on 4 farms (40% of the milk-producing farms) on the cattle and sheep–goat farms. Also, 68% of HNV farms had stocking density values below 1.2 livestock units per UAA for beef cattle, and 53% of sheep–goat farms had below 0.2 livestock units per UAA. There were no significant differences between production volumes calculated by the CC and those from our calculations based on farmer-reported number of animals sold. Biodiversity values of the meat-producing HNV farms negatively related to their meat productivity (Pearson $r = -0.353$, $p = 0.014$, $n = 39$). There were several clear outliers in both datasets (Fig. 3).

4. Discussion

Our results demonstrated considerable variation in most environmental impacts and biodiversity values among farms operating under generally similar principles, that is, HNV farming systems with extensive use of SNG for ruminant production and low external inputs. This is not surprising, considering the wide variation in regional and local solutions in traditional farming systems to adapt to diverse biogeographical contexts (Lomba et al., 2019). It also reflects the extent to which some of the traditional farming systems have modernised their ruminant production by increasing the use of arable land and purchased feed to complement forage from SNG.

Many farms in Finland, Estonia and France, and two in Greece, do not rely entirely on biodiverse SNG to support their production – so-called partial HNV farming systems (Keenleyside et al., 2014). In northern Europe, a limited grazing period makes farms rely on winter fodder, often grown on arable land (silage from cultivated rotational grassland complemented by some cereals and grain legumes), while in southern regions, the summer drought often pushes farms to purchase fodder. Dairy is particularly prone to such partial intensification, as illustrated by farms in France and Estonia. In some cases, as in Finland, ruminant farms may manage relatively small areas of SNG because of public subsidies, becoming remnant HNV farming systems (Keenleyside et al., 2014). At the other end are whole farm HNV farms, where the whole farm business is managed as a low-intensity system, often in a wider landscape of similar farms, as is the case in Spain and Greece. Many of these have not undergone intensification because of low productivity land and/or their presence in socio-economically marginal regions, as is the case with mountainous regions and agroforestry systems in the Iberian Peninsula (Española et al., 2017).

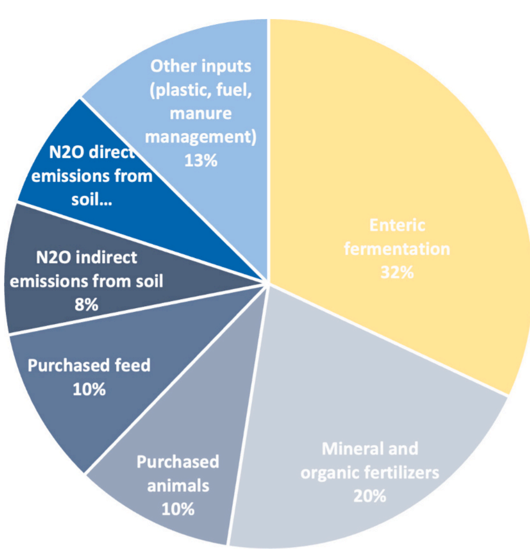

Fig. 2. Contribution of main High Nature Value farming practices to overall greenhouse gas emissions.

The highest GWP_{100} per ha and production of farms was in Greece, which can be explained by their particularly low productivity across all categories of production and, especially, the small ruminant production of sheep and goats common for HNV farms in the region (Ripoll-Bosch et al., 2013). Such production is commonly associated with higher GWP_{100} compared with that of cattle (Bellarby et al., 2013). Our study included several farms with a particularly low productivity level. HNV farms in our study presented low stocking density similar to previous studies on low-input farming systems by the Joint Research Centre, Institute for Environment and Sustainability, et al. (2008), resulting in average values of GWP_{100} of 5 t CO_2 eq ha^{-1}, which is low compared with other intensified production systems with stocking density values of above 1.2 (Eurostat, 2023). In the low-input, ruminant-based system, over half of the overall CO_2 eq emissions originate from the enteric fermentation process, and CH_4 emissions depend mostly on the number of animals rather than the production practices as in intensified systems, which may increase the overall emission impact if not accounting for production volumes (Garnett et al., 2017). The use of low-digestibility feed (i.e. from SNG) slows weight gain and lowers the breeding efficiency of free-moving ruminants, further lowering the emission efficiency of animal production (e.g. Bragaglio et al., 2018). Further, low stocking density values reduce the pressure on land, even favouring the maintenance of biodiversity (Piipponen et al., 2022).

Most of the land in HNV production in Spain is commonly used for extensive grazing, often in agroforestry systems (Española et al., 2017), leading to low emissions per ha but particularly large land occupation per ha, especially when expressed per product output. In the case of HNV farming systems, use of SNG unsuitable for arable crop production precludes food-feed competition and increases the efficiency of the whole food system by utilising a variety of resources over the landscape (Zira et al., 2023). As illustrated with an LU model, substituting SNG with arable land on HNV farms in Finland would increase their emissions, N balance and arable land occupation (Torres-Miralles et al., 2022).

The environmental impacts of HNV farms in the boreal region, especially of low-input beef production using a mix of semi-natural and arable forage, were relatively low, especially when expressed per product. The farms from France (Atlantic region) fell in between in most of their impacts: HNV farms in our sample mostly produce beef on fertile riverine pastures, which allows relatively low land occupation and moderate productivity. The water use of farms in these bioregions with abundant rainfall was low, but use of fossil fuel was relatively high.

Many HNV farming practices, such as circulation of nutrients with on-farm manure, reliance on biological N fixation in native vegetation of SNG, and utilization of legume–grass mixtures on grassland leys, are characteristic of low-input systems. Our assessment indicates that the N balance of many farms was negative, which reduces nutrient losses to the environment where nutrient exports may not be entirely compensated for by management practices (as in Karlsson and Röös, 2019).

Farms with the highest share of SNG, such as wooded and coastal

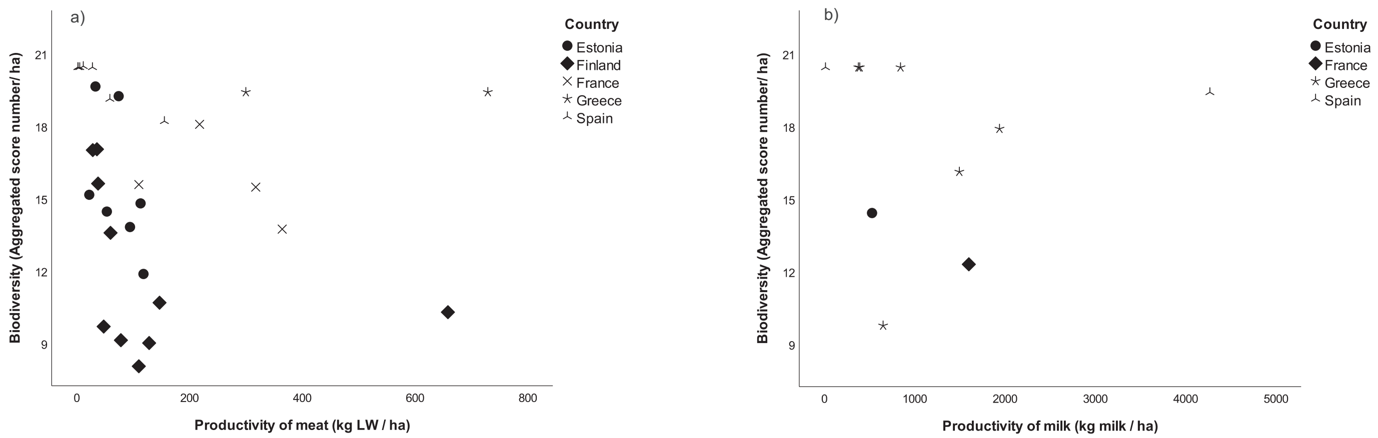

Fig. 3. Biodiversity of farms related to their productivity of a) meat (kg live weight - LW) and b) milk (kg ECM milk).

pastures, had the highest biodiversity values as well as land occupation per product. This is a direct result of the way the SALCA-BD method assigns biodiversity values to different LU types within farms. High biodiversity values for semi-natural and low-intensity permanent grassland in SALCA-BD are derived from numerous research in Europe on the importance of low-extensity grazing for species associated with open and semi-open habitats (e.g. Rodríguez-Ortega et al., 2014). The whole concept of HNV farmland and an HNV farmland system has been developed from the premise of production being compatible with maintenance of farmland biodiversity (Lomba et al., 2023). Biodiversity values of other LU types on the farms were similar across countries, reflecting a relatively low intensity of LU also on fields, as well as the fact that most characterization factors for different intensity levels vary relatively little (Hallström et al., 2022).

The use of semi-natural habitats as a forage resource reduces the requirements of purchasing feed, reflected in high feed autonomy values – above 83% – for the HNV farms, except for Greek sheep–goat HNV farms, which showed 46% because of feed purchases. Recent studies showed that pastoral systems based on >85% of semi-natural habitats are less dependent on external inputs and have lower ecotoxicity, LU and human edible food conversion than more intensive systems (Zira et al., 2023). This also reduces externalised impacts of fodder production outside of livestock farms on biodiversity in fodder-producing regions (Kyttä et al., 2023). Biodiversity scores here do not include the externalised impact on biodiversity from the use of concentrates or purchased feeds because their origins are not available. Assuming that such purchased feed is derived from biomass from either leys (silage or hay) or cereals, replacing biomass from a land unit of SNG with a unit of cultivated field in Europe would reduce the biodiversity value by 2–4 times, according to SALCA-BD (Table 2). However, the impact will depend on the biomass yield from the respective LU types, as well as the impact assessment method for externalised impacts of products (Kyttä et al., 2023).

The environmental impact assessed by product depends directly on the productivity (i.e. yield). In our data, farms with both low inputs of fuel and low yields had relatively high FRS per unit of product, meaning high extraction costs in relation to a low use of fuel. Especially extensified systems based on transhumance (i.e. movement of herds between low- and highlands to optimise pasture use) in agroforestry show relatively low emission intensities that are comparable to very intensified livestock systems (Pardo et al., 2023). When farms purchase external inputs, such as feed, but are unable to improve productivity, their overall GWP_{100} per ha also increases. Only if the above external inputs are adequately transformed into increased yields are the environmental impacts of the products reduced, as illustrated also in a global review (Nemecek et al., 2011). Similarly, incorporation of some arable land into production in this context, where feasible, may allow increasing productivity of HNV farms without drastic reduction in their overall biodiversity, as is the case here with some meat farms from Estonia and France and a dairy farm in Spain. HNV farms with exceptionally high productivity levels here could achieve this either when maintaining high biodiversity values using SNG in full (a whole HNV farming system in Greece) or with low biodiversity values and the use of SNG (a remnant HNV farming system in Finland). In both cases, this led to a reduction in the farm's feed autonomy through reliance on purchased feed from the arable land and high stocking levels. The question of how to improve the productivity of animal-based food while maintaining a high output of ecosystem services and minimal environmental impacts needs to be carefully scrutinised in each farming system case and region by developing LCA and other assessment methods (Bragaglio et al., 2020; Ripoll-Bosch et al., 2013; von Greyerz et al., 2023).

Although the study results are not directly comparable to other LCA studies because of methodological differences, our estimates fall within those from a few similar studies on farming systems that correspond with HNV farming. The mean GWP_{100} estimates here for extensive Mediterranean systems for small ruminant production of lamb and goat (30.6 kg CO_2 eq kg LW^{-1}) are lower than those for lamb meat in Mediterranean pasture-based systems and mixed systems (51.7 and 47.9 kg CO_2 eq kg^{-1}, respectively) (Ripoll-Bosch et al., 2013). The GWP_{100} results for lamb approach the highest range (< 12.5 to >25 kg CO_2 eq kg^{-1}) for extensive systems in the global review of Poore and Nemecek (2018). The results for beef (35 kg CO_2 eq kg LW^{-1}) fell in the lower range (< 25 to >75 kg CO_2 eq kg^{-1}). Impacts estimated for cow dairy products (1.8 kg CO_2 eq kg ECM $milk^{-1}$) are similar to those for products from extensive pastoral smallholder farming systems in France (French livestock institute, 2022) and fall under the lowest Poore and Nemecek standardised values for dairy (< 1.8 to >5 kg CO_2 eq kg^{-1}). The values for goat and sheep dairy (3.6 kg CO_2 eq kg ECM $milk^{-1}$) are, however, higher than those reported in the literature. The reasons could be a particularly low output of sheep–goat dairy in the extensive, mostly mixed, production in the Mediterranean region.

The farms enrolled in the study are typical ruminant production systems for their respective regions, but because of the paucity of data on HNV farms, it was not feasible to select them to be representative of their regions. This sets limits on the generalization that can be drawn from the results here. The significance level of the relationship between productivity and biodiversity should be treated with caution because of a small sample size with considerable variation in values and outliers. Other potential limitations are due to the availability of primary data, particularly for semi-natural habitats, which affects the assumptions in come critical estimates made for LCA (i.e. yield or energy contents), as well as externalised impacts from purchased feed unaccounted for in this study. However, the study contributes to filling the gap in quantitative data in relation to HNV farming systems and similar production systems.

It also adds to the methodological advances of integrating biodiversity into the LCA approach specifically targeting farmland LU in the European context. The strength of this approach is that it is based on an inventory of the habitats of a farm and a detailed list of production practices (commonly collected as part of LCA) without collection of biological data from farms. Therefore, the method allows the assessment of the same production system under different levels of management intensity, the latter having a considerable impact on biodiversity within farmland (Herzon et al., 2008). Extending SALCA-BD to off-farm activities, such as the production of imported feed, would be an important step forward. An open question remains about the extent to which HNV farms, with their inherently lower yields than those of intensive farms, have the potential to supply animal source foods in quantities sufficient for healthy diets domestically and beyond while still maintaining trade. Some recent modelling suggests that this can happen only on the condition of considerable dietary changes towards more plant-based foods in Europe (Röös et al., 2022; Schiavo et al., 2023).

5. Conclusion

This study is the first to examine the environmental impact, integrated with biodiversity expert-based assessment, of HNV farming systems among key regions in Europe. Taking such diversity into account in measuring the multiple negative and positive impacts of production, and therefore also deriving recommendations, is a challenge, as illustrated in this cross-country study. The extensive production on HNV farms enables food production under conditions of low use of external inputs, while maintaining farmland biodiversity. As CH_4 from enteric fermentation remains a key contributor to overall emissions in ruminant-based farming systems, and other environmental impacts of food production are linked to the production volumes, some improvement in productivity on HNV farms may be feasible. However, further environmental impact assessments need to better capture the potential of multifunctional farming systems to contribute to overall sustainable LU despite their low productivity of animal-based food. The sustainability of food derived from animals depends not only on how production is organized but also on how much of the food is consumed. Further research is necessary to evaluate the role of HNV farming systems in the overall production of livestock in transitioning to more sustainable and healthier food systems.

CRediT authorship contribution statement

M. Torres-Miralles: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **V. Kyttä:** Writing – review & editing, Methodology. **P. Jeanneret:** Writing – review & editing, Validation, Methodology, Formal analysis. **M. Lamminen:** Writing – review & editing, Validation, Methodology. **P. Manzano:** Writing – review & editing. **H.L. Tuomisto:** Writing – review & editing, Validation, Supervision, Methodology. **I. Herzon:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

Declaration of competing interest

Torres-Miralles, Miriam reports financial support was provided by Finnish Cultural Foundation. Torres-Miralles, Miriam reports financial support was provided by August Johannes and Aino Tiuran Foundation. Torres-Miralles, Miriam reports financial support was provided by Helsinki Institute of Sustainability Research. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be uploaded in the repository after the paper gets accepted

High Nature Value farming systems in Europe: a dataset encompassing the environmental impact assessment of farms and extensive ruminant food products. (Original data) (Figshare)

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Appendix A

Distribution of High Nature Value farms included in the study within various biogeographical regions in Europe. Base map: ©European Union, Copernicus Land Monitoring Service 2023, European Environment Agency

Appendix B. Example of the selection of farming practices for grassland type I (unproductive) (semi-natural grassland)

Habitat-type I	Habitat-type II	Management level I	Management level II	Management level III	Option	Selection (x)
Grassland	Grassland I (unproductive)	Fertilization		Frequency (disturbance)	a. 0	x
				Frequency (disturbance)	b. 1–2	
				Frequency (disturbance)	c. 3–4	
				Frequency (disturbance)	d. ≥ 5	
				Date (disturbance)	a. beginning of January < x < end of May	
				Date (disturbance)	b. beginning of June < x < end of August	
				Date (disturbance)	c. beginning of September < x < end of December	
				Quantity	b. very extensively used meadows	

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Habitat-type I	Habitat-type II	Management level I	Management level II	Management level III	Option	Selection (x)
				Quantity	c. extensively used meadows	
				Quantity	d. low-input meadows	
				Quantity	e. moderate intensive meadows	
				Quantity	f. intensively used meadows	
				Quantity	g. very intensively used meadows	
				Fertilizer type	urine slurry	
				Fertilizer type	slurry	
				Fertilizer type	fresh manure	
				Fertilizer type	decomposed manure	
				Fertilizer type	compost	
				Fertilizer type	ammonium salpetre	
				Fertilizer type	urea	
				Fertilizer type	other	
		Plant protection	weed control	Frequency (disturbance)	a. 0	x
				Frequency (disturbance)	b. 1–2	
				Frequency (disturbance)	c. 3–4	
				Frequency (disturbance)	d. $\geq$ 5	
				Date (disturbance)	a. beginning of January < x < end of May	
				Date (disturbance)	b. beginning of June < x < end of August	
				Date (disturbance)	c. beginning of September < x < end of December	
				Herbicide quantity	b. <25% of the field area	
				Herbicide quantity	c. 26% < area < 50%	
				Herbicide quantity	d. 51% < area < 75%	
				Herbicide quantity	e. 76% < area < 100%	
				Herbicide type	a. selectively impacting herbicide	
				Herbicide type	b. not selectively impacting herbicide	
				Herbicide (single plant application)	yes	
				Herbicide (single plant application)	no	x
			Mouse control	Mouse control	no mouse control	x
				Mouse control	traps	
				Mouse control	baits	
				Mouse control	gassing	
		Cutting		Utilization number	a. no utilization	x
				Utilization number	b. very extensively used meadows	
				Utilization number	c. extensively used meadows	
				Utilization number	d. low-input meadows	
				Utilization number	e. moderate intensive meadows	
				Utilization number	f. intensively used meadows	
				Utilization number	g. very intensively used meadows	
				Date (disturbance)	a. beginning of November < x < end of February	
				Date (disturbance)	b. March	
				Date (disturbance)	c. April	
				Date (disturbance)	d. May	
				Date (disturbance)	e. June	
				Date (disturbance)	f. July	
				Date (disturbance)	g. August	
				Date (disturbance)	h. September	
				Date (disturbance)	i. October	
				Mowing technology	a. motor mower	
				Mowing technology	b. rotary mower	
				Mowing technology	c. rotary mower with conditioner	
				Height	a. < 8 cm	
				Height	b. $\geq$ 8 cm	
				Hay ball (silage)	yes	
				Hay ball (silage)	no	x
				Autumn grazing	yes	
				Autumn grazing	no	x
		Grazing		Utilization number	a. no utilization	
				Utilization number	b. very extensively used pastures	
				Utilization number	c. extensively used pastures	x
				Utilization number	d. low-input pastures	
				Utilization number	e. moderate intensive pastures	
				Utilization number	f. intensively used pastures	
				Utilization number	g. very intensively used pastures	
				Date (disturbance)	a. beginning of November < x < end of February	
				Date (disturbance)	b. March	
				Date (disturbance)	c. April	
				Date (disturbance)	d. May	
				Date (disturbance)	e. June	x

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Habitat-type I	Habitat-type II	Management level I	Management level II	Management level III	Option	Selection (x)
				Date (disturbance)	f. July	x
				Date (disturbance)	g. August	x
				Date (disturbance)	h. September	x
				Date (disturbance)	i. October	
				Animal density	a. very extensively used pastures	
				Animal density	b. extensively used pastures	x
				Animal density	c. low-input pastures	
				Animal density	d. moderate intensive pastures	
				Animal density	e. intensively used pastures	
				Animal density	f. very intensively used pastures	
				Animal species	cow (milk production)	x
				Animal species	cow with calf	x
				Animal species	cattle <1 year	x
				Animal species	cattle 1–2 years	x
				Animal species	cattle >2 years	x
				Animal species	mare with colt	
				Animal species	other horses/colts	
				Animal species	goat	
				Animal species	sheep/milk sheep	
				Animal species	deer	
				Animal species	stag	
				Animal species	bison <3 years	
				Animal species	bison >3 years	
				Animal species	llama <2 years	
				Animal species	llama >2 years	
				Animal species	alpaca <2 years	
				Animal species	alpaca >2 years	
			Maintenance (cleaning)	Maintenance type	no maintenance	x
			Maintenance (cleaning)	Maintenance type	spring tine weeder	
			Maintenance (cleaning)	Maintenance type	cleaning cut	
			Maintenance (cleaning)	Maintenance type	mulching	
			Maintenance (cleaning)	Mowing technology	a. motor mower	
			Maintenance (cleaning)	Mowing technology	b. rotary mower	
			Maintenance (cleaning)	Mowing technology	c. rotary mower with conditioner	
			Maintenance (cleaning)	Height	a. < 8 cm	x
			Maintenance (cleaning)	Height	b. ≥ 8 cm	x

Appendix C. Example of the calculation of biodiversity score for one High Nature Value (HNV) farm based on SALCA-BD scores

HNV field type	SALCA-BD field type	Hectares	SALCA-BD score	Total
Semi-natural grassland	Grassland I (unproductive)	47.0	19.5	917.2
Permanent grassland	Grassland II (moderate productive)	0.0	0.0	0.0
Fallow	Fallow	3.0	15.1	45.2
Grain legumes	Grain legumes	15.0	5.6	84.3
Cultivated grassland	Leys (artificial meadows)	57.0	4.6	263.5
Winter cereals	Winter cereals	45.0	6.8	305.7
	Total	167.0	–	1615.9
Biodiversity score HNV farm (aggregated totals / total hectares farm)				9.7

Appendix D. Aggregated values for biodiversity and four environmental impact categories: global warming potential (GWP_{100}) (kg CO_2 eq), fossil resource scarcity (FRS) (kg oil eq), land use (LU) (m^2a crop eq) and water scarcity (WS) (m^3) per country in hectares. Means and (± *SD*)

Bioregion	Country	Product	Number of farms	GWP_{100} (t CO_2 eq ha^{-1})	LU (m^2a crop eq ha^{-1})	FRS (kg oil eq ha^{-1})	WS (m^3 ha^{-1})	Biodiversity (aggregated score number ha^{-1})
Boreal	Finland	Beef	7	2 (± 0.9)	5116 (± 507)	0 (± 1)	−20 (± 34)	18 (± 3)
		Beef–sheep	2					

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Bioregion	Country	Product	Number of farms	GWP_{100} (t CO_2 eq ha^{-1})	LU (m^2a crop eq ha^{-1})	FRS (kg oil eq ha^{-1})	WS (m^3 ha^{-1})	Biodiversity (aggregated score number ha^{-1})
		Sheep	2					
	Estonia	Beef	7	1 (± 0.4)	5175 (± 461)	0 (± 0)	−5 (± 6)	15 (± 3)
		Dairy	1					
Mediterranean	Greece	Beef	2	12 (± 10.6)	5449 (± 172)	19 (± 28)	−8 (± 12)	20 (± 1)
		Beef–sheep	2					
		Sheep–goat	3					
		Goat	1					
	Spain	Beef	2	2 (± 3.0)	5193 (± 433)	17 (± 27)	5 (± 14)	18 (± 2)
		Beef–sheep–goat	1					
		Sheep	2					
		Sheep–goat	2					
		Goat	1					
		Dairy	1					
Atlantic	France	Beef	4	7 (± 3.6)	5373 (± 285)	0 (± 0)	−6 (± 8)	15 (± 3)
		Dairy	1					
All combined		Beef	22	5 (± 4.1)	5261 (± 372)	7 (± 15)	−4 (± 11)	17 (± 1)
		Beef–sheep	4					
		Beef–sheep–goat	1					
		Sheep	4					
		Sheep–goat	5					
		Goat	2					
		Dairy	3					

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