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Deliverable 1.3 Mapping and analysis of impacts/externalities of livestock farming, and related indicators

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LIST OF ACRONYMS / ABBREVIATIONS

NAME	MEANING
SLR	Systematic literature review
ELP(s)	European Livestock Production(s)
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
SSS	Singel search strategy for systematic literature review.
MSS	Multiple search strategy for systematic literature review.
PICO Framework	Population, Intervention, Comparison, and Outcome Framework
AHW	Animal health and welfare
RS	Reference Scale
IP	Impact Pathway
GHG	Green House Gas Emissions
EF	Emission factor
DMI	Dry Matter Intake
NDF	Neutral Detergent Fibre
EE	Ether Extract
AWIN	Animal Welfare Indicators
n-LCA	Nutritional Life-Cycle Assessment
ALYS	Animal Life Years Suffered
AL	Loss of Animal Lves
MAL	Morally Adjusted Animal Lives
DIAAS	Digestible Indispensable Amino Acids Score
NRF	Nutrient Rich Food
NRD	Nutrient Rich Diet
HENI	Health Nutritional Index
AHEI	Alternative Healthy Eating Index
FU	Functional unit
NFU	Nutritional Functional Unit
PMV	Priority Micronutrient Value
NFE	New Food Equivalent
RDI	Reference Daily Intake
EIWDVS	Environmental impact weighted daily value score

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1. Executive Summary

This research completed eight systematic literature reviews (SLRs) using the PRISMA and PICO methodologies to map and measure indicators and externalities measuring the positive and negative (sustainability) impacts of European livestock production systems (ELPs). The eight SLR represented eight respective impact categories (IC): (1) Economic, (2) True cost accounting (TCA), (3) Social, (4) Greenhouse gases (GHG), (5) Animal health and welfare (AHW), (6) Soil health, (7) Biodiversity, and (8) Nutritional life-cycle assessment (n-LCA). To address the research question, the chosen methodology and experimental design was a 'multi-systematic literature review', which integrated approaches of both single (SSS) and multiple search strategies (MSS). Whilst this ensured appropriate flexibility in MSS (e.g. proximities, truncations, and inclusion criteria) for different ICs', all search strategies abided by co-agreed search terms (SSS), for example, species, system, and management type, geographical distribution, and primary research article.

A total of 518 indicators were derived from the economic MSS. Whilst most of these indicators, their measurement, and associated data built a positive narrative of the economic impact of ELPs, indicators were limited to one species type, namely, cattle, and/or one unit of measurement/indicator, namely profitability (80%) – especially in western Europe. The outputs of the MSS revealed - There is a need to need to unify the terminology surrounding economic indicators to improve replicability, comparability, and transparency in livestock research. Here the FADN methodology, which is already established and commonly used across Europe, is highly recommended as an obvious choice to guide this process. Further, the transition to FSDN also provides an opportunity to expand indicators of economic objectives that are not yet commonly assessed in the literature (e.g., fairness, resilience, diversification) and become a reference in these areas.

Looking at the positive and negative impacts of ELPs, which may be external to market prices, the TCA MSS resulted in a higher number of identified externalities with various monetary values applied. In total, 35 indicators across 16 externalities were identified. Dairy cattle represented the most assessed animal species (64%) with almost all (94%) studies considering environmental externalities only (mostly climate change), and limited number (4%) considering social externalities. Overall, results show that two major types of methods have been applied for the estimation and calculation of the monetary value of the externalities: (1) studies that estimate an "own" abatement cost curve, based on the data that had been gathered in the particular study, and (2) studies that use "available" monetisation factors for the calculating the monetary value of the externality.

The most significant takeaway from the results of the MSS for the social IC is how under-researched indicators measuring the sustainability of ELPs is. Nonetheless, a total of 96 indicators were identified,

providing a mostly “negative” narrative of the social impact of ELPs. Importantly, due to significant gaps in the assessment of the social impact of ELPs, this narrative relies on isolated case studies. Notwithstanding this, local employment, fair salary, and occupational health and safety were assessed most – with ‘workers’ emerging as the most consistently evaluated stakeholder group. There was significant variation in the number of indicators per social ‘impact subcategory’, ranging from one to thirty – highlighting a reliance on data availability rather than on standardized methodological guidance. Thus. in summary, due to the limited number of studies, their fragmented scope, inconsistent methodologies, and poor data transparency, interpretation of these MSS results need caution. These limitations are a major barrier for a coherent and reliable picture of social sustainability impact of ELP systems. It is recommended to develop a standardized set of impact subcategories, indicators, and inventory indicators, methodological standardisation regarding weighting, and improved data quality reporting. These requirements are fundamental for a advancing measurements of the social impact ELPs

In terms of impact, the “choice” of the functional unit became one of the most significant takeaways from the GHG MSS. This MSS focused on two key GHG for this IC: enteric methane (CH4) and manure management. For enteric methane, 183 different ‘prediction equations’ were derived estimating emission factors (EF). In total, there were 243 CH4 EFs from 13 countries with daily matter intake (DMI) becoming a key factor for enteric CH4 production prediction (all ruminants). Indeed, EF for ammonia (NH3) and N2O were most significant within manure management, representing 654 EFs from 16 countries, and 421 EFs from 17 countries respectively. In addition, milk production and composition variables are key factors to predict CH4 yield, whereas milk composition and animal variables are key factors to predict CH4 intensity. For EFs and tier measurements, CH4 emission conversion factors (dairy/beef) for specific regions are preferred to improve CH4 production estimates in national inventories – as addressed by the IPCC in 2019.

Whilst 100 AHW indicators were derived from the respective MSS, lameness and body condition score were most popular. Nonetheless, subjectivity and inadequate standardization(s) of the indicators was a major limitation – further reflected in that AHW indicators are measure predominately qualitatively rather than quantitatively. Despite these limitations, an advantage of the identified AHW indicators is their broad applicability, applicable across different global production systems, and studies using and measuring AHW indicators is gaining significant research interest – reflected within the MSS results – especially for animal-based indicators. But the need for a standardized scoring framework will remain a limitation and is essential to normalize indices and integrate models for AHW.

Data from the 472 indicators used to measure the impact of ELP on the chemical, biological, and physical quality, fertility, and overall health of European soils, there was an overwhelming positive narrative developed. Whilst chemical indicators were most frequent, significant emphasis was placed on the effect of livestock byproducts (slurries/manures) on the health of soils and associated yield, production, and productivity. Whilst nutrient run-off (leaching), particularly for phosphorous, was highlighted as a major

issue, the positive impact of cattle and pig slurry/manures on various indicators of soil health was substantial. Soil health indicators such as pH, SOC (13%-87%) (including biomass and total carbon), nitrogen, phosphorous (up to 47%), improving/increasing significantly under different applications. Indeed, there was evidence that such soil slurry treatments caused increases in microbial growth, with significant increases in earthworm populations (84%) in permanent pastures, a 100% increase when pig slurry (also increases in Anecic earthworms, Endogenic earthworms, macroacroarthropods and mollusks) applied, and further increases in enzymatic activities, in particular β-glucosidase and β-glucosaminidase activity (10%-60%) under cattle manure treatments – with further improvements on soil aggregate stability. Grassland renewal was criticized as a cost-effective method to improve soil health, with good management of ("old") grasslands, e.g., maintaining desirable grasses by grazing, ample fertilization, irrigation and preventing and ameliorating soil compaction recommended instead. In the literature, stocking density became a significant indicator, as high rates often resulted in higher net pasture accumulations due to higher fertilization, but also lead to soil compaction, erosion and degradation of physical attributes overtime – but evidence also suggests that livestock exclusion will not alleviate soil compaction.

Similar soil health, the results of the biodiversity MSS found indicators measuring (mostly) a positive impact of ELP. Thus, the presence of livestock was frequently associated with positive impacts on biodiversity, in fact, conversely, the absence of livestock grazing with associated with negative effects. In total, 34 studies reported positive impacts, whilst 21 reported negative impacts. Cattle were the highest research livestock species and extensive livestock production received the highest for management type. There was significance on the positive impact of ELP on the diversity of plant, invertebrate, and vertebrate communities, ecological infrastructure, and the maintenance of habitat quality for fauna. Despite this, similar to some findings for soil health, grazing intensity is predominantly linked to negative outcomes, namely, reductions in plant and invertebrate diversity, declines in mammal and bird presence and habitat availability.

Adjusting the functional unit (FU) within conventional environmental life-cycle assessment (LCA) to incorporate the nutritional, particularly the quality/bioavailability of animal sourced foods (ASF) has gained significant research attention. The results of this MSS (n-LCA) support the increasing evidence that incorporating this FU into environmental LCA reduces the reported negative impact of ELP significantly. Whilst 63% of all studies were published from 2023-2024, a total of 56 nutritional indicators were derived, but those incorporated in n-LCA, becoming the NFU of environmental assessments, were dominated by measurements of protein quality, density, and bioavailability – especially Digestible Indispensable Amino Acids Scores (DIAAS) and Nutrient Rich Food / Nutrient Rich Diet (NRF/NRD). The significance of these nutritional indicators within n-LCA, decreasing beef CO_2 emissions from 30-97%, establish a more balanced view between livestock production, public health, and the environment. Foremost, these results suggest

that dietary recommendations should consider not only the environmental impact of ruminant meat but also its protein bioavailability.

Overall, coupled with 16 externalities, this research has mapped 1,517 indicators from several scientific literature databases, which measure the positive/negative social, economic, and environmental impact of ELP.

Firstly, 518 indicators were derived from the economic MSS. Whilst the data from indicators developed a positive narrative of the economic impact of ELP, results were hugely reliant on 'profitability' as a measure/indicator, particularly for dairy production. Moreover, 35 indicators were identified for TCA, similar to economics, dairy production dominated the research focus. In total, 16 externalities were derived, but almost all of them focused on environmental impact – especially climate change. Despite a total of 96 indicators resulting from the social MSS, the most significant finding was how under-researched this strand of sustainability for ELP remains. Thus, a relatively negative narrative was derived from indicator values, but the limited number of studies, their fragmented scope, inconsistent methodologies, and poor data transparency, emphasizes caution when interpreting their results.

In relation to GHG, 183 prediction equations were established, with DMI and production variables (milk yield etc.) maintaining significance, but the choice of the FU became most critical, whilst regional-specific EF(s) became an important recommendation – as noted by IPCC. The significance of the FU is clearer within the results of the (environmental) n-LCA MSS, wherein, despite a wide-range of nutritional indicators (n=56), three were of high significance within (carbon) n-LCA models: DIAAS, NRF, and NRD. Here findings reveal substantial reductions in the climatic impact of ELP – from a nutritional (consumption) level. The results of the AHW MSS were similar to the social MSS regarding the number of identified indicators (n=100) and the limitations of the research area. Here, a major drawback is the inadequate standardizations of indicator values, thus, it is essential to normalize indices for AHW indicators, enabling the integration of models. More detailed outputs were found within the soil health MSS, wherein a total of 472 indicators were established, resulting in a significantly positive narrative on the impact of ELP for this IC (especially the impact of livestock slurries/manures), similarly, values/data of the 57 indicators for biodiversity developed a positive narrative – but, importantly, 'over grazing' was highlighted as a critical 'threshold' for this positive impact for both ICs.

Although this research has mapped a large number of indicators to address the principle research aim, it is clear that there are significant research gaps and limitations measuring the social, economic, and environmental impact of ELP. Irrespectively, results measuring the impact of ELP should be considered with caution, as several trade-off exist, coupled with data and modelling limitations, and the significance of experimental approaches. Notwithstanding this, despite the results of the social and AHW MSS, albeit substantially limited, this results from this research have developed a significantly positive narrative of the impact of ELP. The findings from this research reinforce that policy-making must maintain and support the

important role that ELP plays within a productive and environmentally sustainable multifunctional European landscape.

2. Introduction

2.1. European Livestock Production

Agriculture's unique economic position, fundamental role in food security and consequential environmental footprint is a well-known trade-off (McGuire et al., 2023), so much, that it is embedded within several United Nations Sustainable Development Goals (UNSDGS) and directly linked to six (SDG 2; 3; 6; 12; 13; 15) (Shahmohamadloo et al., 2022; Ladha et al., 2020; Streimikis and Baležentis, 2020). For Streimikis and Baležentis (2020), sustainable agriculture conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable. Despite the proclaimed benefits, major environmental challenges exist, with agriculture accounting for significant (12%) annual greenhouse gas (GHG) emissions (CO_2e) (Rosa & Gabrielli, 2023).

European livestock production systems (ELPs) occupy around 28% of the land surface of the European Union (EU) (Simpson et al., 2015), whilst there are societal concerns about the welfare of farmed animals, particularly in Western societies. For example, 84% of Europeans believe that the welfare of farmed animals should be better protected than it is now (European Commission, 2023), whilst the EU Common Farmland Bird Index has dropped by 36% and the EU Grassland Butterfly Index declined by 30%. Notwithstanding this, livestock grazing can positively affect biodiversity in pastures by creating and maintaining sward structural heterogeneity, due to nutrient cycling and propagule dispersion, whilst there is evidence that abandoning grazing in certain environments may not result in an increase to biodiversity, and in some instances can cause further loss Filazzola et al., (2020). Further, in the EU, 65-75% of agricultural soils, a vital carbon storage system, have high nutrient inputs, with ~60 to 70% of soils in an unhealthy state (Veerman et al., 2020)

Indeed, often overlooked in research and development (R&D), ELP plays a vital role within the European multifunctional, social–ecological system, delivering not only marketable goods but also a wide range of public goods, both Rodriguez-Ortega et al., (2014) and Ryschawy et al., (2017) argue that ELPs provide ecosystem services, such as climate regulation, flood and fire prevention, and recreation. In addition, livestock production maintains 30% of High Nature Value farmland across Europe, contributing to the maintenance of soil fertility, farmland biodiversity, and a suite of social public goods including food security, rural vitality and culture (Steinfeld *et al*., 2013; Plieninger *et al*., 2013) – but these contributions lack market value and are often unaccounted for.

During a time when the EU continues to grasp and position itself within a new era of geopolitical unpredictability, the mix of (1) agri-environmental challenges, (2) global increases ruminant population

(66%) from 1960 to 2017 (FAOSTAT, 2017), (3) record high feed, fuel, and energy prices, (4) tightening environmental restrictions, and (4) increasing trade/competition, have forced EU livestock farmers to scale back production, with total EU cowherd is set to decrease by 9.1% by 2032. This causes significant social, economic, and environmental challenges for the EU and policy-making within the European Commission (EC). In response, in R&D, a central approach to addressing, measuring, and/or mapping the social, economic, and environmental impact (both positive and negative) of ELP, is indicator-based research methods.

2.2. Sustainability indicators

There is a lack of methodologies to simultaneously quantify all of the contributions of livestock production or to analyse their interrelationships (Ryschawy et al., 2017). Thus, there is a need for robust, data-driven 'measure, report and verify' protocols/standards. European agriculture must urgently adopt approaches that utilise scientifically informed data-driven protocols, which, measure farm (baseline) performance using sustainability indicators, and deliver continuous targeted knowledge-exchange (KE) to strategically improve on-farm sustainability. Sustainability indicators are often defined as somewhat 'integrated / composite' variable(s), which bring multiple variables together to measure phenomena that is typically unobservable or difficult to measure. Often, several indicators are grouped and measured, either qualitatively and/or quantitatively, to measure an 'impact category' (IC) (also referred to a metric) for a sustainability dimension, for example in an environmental context, climate change, biodiversity, soil health, etc.

For agriculture, a multitude of examples exist for indicator-based research. Earlier work by Gomez et al., (1997) built upon previous work by Smyth et al., (1993) to develop a suite of 'field indicators' for sustainable farming, whilst more noteworthy indicator frameworks include the FAO's Sustainability Assessment of Food and Agriculture Systems (SAFA) guidelines and the United Nation's Environment Programme (UNEP).

To define an indicator, the following definition by Alary et al., (2022) is accepted, an indicator is defined as a quantitative or qualitative "variable which supplies information on other variables which are difficult to access and can be used as a benchmark (to characterize and evaluate the system) to make a decision." Bunge (1975), Maleksaeidi et al., (2014), and Valizadeh and Hayati (2021) have similar definitions of indicators when applied to agriculture, agreeing that they are considered as an observable or computable variable for estimating or measuring dimensions of a concept or macro structure such as agricultural sustainability; whereas, a scale or an index is a synthesis of several effect indicators. Similarly, the environmental and societal impacts originating from ELP leads to costs and benefits that are not (fully) reflected in market prices. These costs and benefits are external as they are borne by society and not by

parties that caused the impacts. External costs and external benefits are both called externalities[1]. According to Rusman et al. (2023), the external costs attributed to EU sourced food production and consumption is 1,455 billion euros.

Broadly, according to Griffin and Steele (1986), external costs exist when "the private calculation of benefits or costs differs from society's valuation of benefits or costs". As a fundamental example, pollution represents an external cost because associated damages are borne by society as a whole, and are not reflected in market transactions (as cited by Koomey & Krause, 1997). Importantly, sustainability does not imply zero externalities. Given the dynamics and complexities of 'sustainable' food systems, the 'risk' and need to measure, or at least account, for externalities is critical.

2.3. Aims and Objectives

2.3.1. Research Aim:

As Task 1.3 of the H2030 STEP UP project, the principle aim of this research, through the identification of indicators, is to map and analyse the impacts (social, economic, and environmental), both positive and negative, including externalities, of ELPs.

2.3.2. Research Objectives:

This research will provide a collation of the positive and negative impacts/externalities of ELPs, placed in different social, economic, and environmental contexts, including potential trade-offs and synergies. Specifically, it will map and analyse specific impacts/externalities, and existing indicators used to measure these impacts, across different impact categories. Firstly, supported with literature and policy sources, at the consortium level, an online workshop was held among research partners to identify the 'impact categories of interest' for the purposes of this research. From this, a total of eight impact categories were identified, agreed, and brought forward for the purposes of this research:

1. **Economics;**
2. **True-Cost Accounting;**
3. **Social;**
4. **GHG Emissions;**
5. **Animal Health and Welfare;**
6. **Soil Health;**
7. **Biodiversity;**

[1] Externalities occur whenever the actions of one party make another party worse or better off, yet the first party neither bears the costs nor receives the benefits of doing so. We define negative externalities as external costs and positive externalities as external benefits.

8. **n-LCA.**

To deliver the research aim, this research is centred on three key objectives.

- **Objective 1:** (*Indicators*)
    - To systematically identify, map, and collate indicators from scientific literature for each (n=8) respective IC.
- **Objective 2:** (*Impact*)
    - From this, to derive the positive and/or negative social, economic, and environmental impact, including externalities, represented by the identified indicators of ELP
- **Objective 3:** (*Data*)
    - From this, to present the quantitative and/or qualitative value (data) for each impact represented by respective indicators.

3. Method

3.1. Multi – Systematic Review:

To address the research question and deliver the principle aim of this task, a ' multi-systematic ' literature review was chosen as the most suitable method. Systematic reviews are commonly completed through either a (1) single strategy/methodology (SSS) or (2) multiple strategy/methodology (MSS). Within a SSS, search terms are fixed, wherein one *joint* search strategy is developed covering all impact categories simultaneously (the most coherent approach), conversely, for a MSS, search terms are flexible and may be developed separately – one independent search for each impact category (the most individual approach). Importantly, both approaches have advantages and limitations:

2.1.1 Single Search Strategy

Advantages:

- Results can then be coded, then organised and distributed to various groups by impact category/indicator for screening
- Aligns with 'one' review, and enables clear reporting of search methodology

Disadvantages:

- Requires coding by impact category/indicator to distribute work by team – may be lots of results initially.

2.1.2 Multiple Search Strategy

Advantages:

- Each team has full control of search terms and running of them, division of workload.

Disadvantages:

- Reporting and consolidating of searches/PRISMA, not all teams will have access to same databases/full text resources.
- Search terms for similar concepts may vary and lead to inconsistency (e.g. Europe).

3.2. Single and Multiple Search Strategy

2.2.1 Development:

Building upon this, in combination with expert consultation, multiple online (consortium) focus groups developed the experimental design and methodology for T1.3. It was agreed that the methodology would combine both the SSS and MSS, using the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) method – guided by the PICO (Population, Intervention, Comparison and Outcomes) framework. Thus, *individual* systematic searches per impact category (e.g. indicator terminology, search truncations, proximities etc.) are conducted by respective experts/leads (MSS approach), these MSS are, however, based on an agreed primary search strategy (e.g. species type, product type etc.) that is the same in all searches (SSS approach).

2.2.2 PRISMA/PICO:

The following sections (2.3-2.6) outline the SSS and the MSS, including the PRISMA and PICO method(s) for this task, and each respective impact category.

Stages of a systematic review under the PRISMA method:

1. Identify the report as a systematic review
2. Provide an explicit statement of the main objective(s) or question(s) the review addresses
3. Specify the inclusion and exclusion criteria for the review
4. Specify the information sources (such as databases, registers) used to identify studies and the date when each was last searched
5. Specify the methods used to assess risk of bias in the included studies
6. Specify the methods used to present and synthesise results
7. Give the total number of included studies and participants and summarise relevant characteristics of studies
8. Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and

confidence/credible interval. If comparing groups, indicate the direction of the effect (that is, which group is favoured)

9. Provide a brief summary of the limitations of the evidence included in the review (such as study risk of bias, inconsistency, and imprecision)
10. Provide a general interpretation of the results and important implications
11. Specify the primary source of funding for the review

The PICO framework for T1.3:

- **Population** = ELP systems (ELPs)
- **Intervention** = livestock production systems and management system: (1) intensive indoor systems; (2) Intensive grazing; (3) Semi-extensive
- **Comparison** = comparison of alternative production and management systems (intensive vs semi-extensive) and associated sustainability impacts.
- **Outcomes** = outputs from indicators within respective production and management systems measuring impact on sustainability variables.

2.3 Search terms/string:

2.3.1 ELP typologies

For the purposes of this task, the 34 ELP systems (e.g. species, system, and management type) composed in Task 1.1 (project Deliverable 1.0) were summarized into the 9 main livestock categories (and products) as follows:

(*dairy cows OR beef sucklers OR fattening cattle OR finishing cattle OR sheep dairy OR sheep meat OR goats OR pigs OR laying hens OR and broilers*)

For management systems within each main livestock category is needed, 3 main systems will be considered:

i. *Intensive indoor systems* (option for conventional / organic for pigs and poultry)

ii. *Intensive grazing* (e.g., ruminants) or outdoor (e.g., pigs and granivores) systems

iii. *Semi-extensive* (grazing or outdoor systems) with option for conventional / organic for ruminants, pigs and poultry

2.3.2 Product type

Caution is needed in searches, as papers focusing on product as opposed to species type may get excluded. For example, indicators measuring the impact of product (e.g. milk, cheese, wool) may not appear if the search is exclusive to 'livestock', 'ruminant', 'dairy' etc. But product is still relevant to aims. Thus, the following search terms were added:

(Milk OR Eggs OR Pork OR Meat OR Cheese OR Mutton OR Veal OR Wool OR Leather)

2.3.3 Indicator terminology

In the literature, different terminologies are used to describe indicators, impact categories, and/or metrics. To ensure the search incorporated the correct breadth of literature, which focuses on respective indicators, after combining an extensive literature search with expert knowledge, the following search terms were added[2]:

"*Indicator*"* OR "*Impact category*" OR "metric*" OR "theme*" OR "aspect*" OR "criteria*" OR "parameter*" OR "sub-theme*" OR "assessment*" OR "measure*" OR "index*" OR "benchmark*"*

2.3.4 Geographical distribution

To use the EU, EEA, and EFTA countries and the UK (n=33)

EU OR European Union OR Austria OR Belgium OR Bulgaria OR Croatia OR Cyprus OR Czech Republic OR Denmark OR Estonia OR Finland OR France OR Germany OR Greece OR Iceland OR Hungary OR Ireland OR Italy OR Latvia OR Lithuania OR Luxembourg OR Liechtenstein OR Malta OR Netherlands OR Norway OR Poland OR Portugal OR Romania OR Slovakia OR Slovenia OR Spain OR Sweden OR Switzerland OR UK OR Great Britain OR England OR Scotland OR Wales OR Northern Ireland

2.4 Inclusion Criteria

1. **Article type**: Original peer-reviewed research articles only!
2. **Datasets**: Three datasets[3] used for all impact categories (1) Scopus (2) Web of Science (3) Pub Med
3. **Year**: 15 year search (2010 – 2015[4])
4. **Language**: Articles must be in English language

2.5 Reviewing

Screening:

- By two independent reviewers using article titles and abstracts to determine their eligibility for inclusion.

[2] For some MSS, this search term proved not to be necessary, as it excluded papers that focused on indicators of respective impact categories, albeit, did not identify/title them as any of these named search terms.
[3] Where necessary, the lead partner for a given impact category may choose to include other datasets. E.g. BIOSIS Previews / CAB Abstracts / Current
[4]This includes 15 years of publications, which is long for systematic reviews – typically covering a 10 year, even 5 year time period. Thus, a shorter time-period is acceptable, whilst including papers before 2005 (e.g. 1992) is also acceptable if the MSS lead partner identifies it as appropriate.

Reviewing:

- A discussion is followed on a case-by-case basis to resolve any conflicts.
- A third independent reviewer may be provisioned to decide the inclusion/exclusion of any articles in case of any further disagreement between the reviewers.

2.6 Multiple Search Strategy

Building upon the above SSS, respective lead partners for all eight impact categories could now develop their own MSS, by furthering their respective search string and confirming inclusion/exclusion criteria appropriately. This may also include supporting/proximity terms (e.g. soil health / soil quality) and any further search truncations and proximities. These respective MSS are now outlined in the following sections.

2.6.1 Economics

For the economic MSS, the final search string contained four modules, targeted at title, abstract, and keywords.

Boolean operators were used to combine the modules, with 'OR' operators within modules and 'AND' operators between modules. Additionally, three more restrictions were introduced to reduce the search to the last 10 years, original peer-reviewed articles, and to articles written in English only. The completed search string is expressed as follows:

- TITLE-ABS-KEY(
    - (Indicator* OR "Impact categor*" OR metric* OR parameter* OR externalit* AND
    - (Economic OR Financial) AND
    - ("dairy cows" OR "beef sucklers" OR "fattening cattle" OR "finishing cattle" OR cattle OR "sheep dairy" OR "sheep meat" OR sheep OR lamb OR goats OR pigs OR "laying hens" OR Broilers OR Milk OR Eggs OR Pork OR Meat OR Cheese OR Mutton OR Veal OR Wool OR Leather or livestock) AND
    - (EU OR EUROPE OR EUROPEAN OR "European Union" OR Austria OR Belgium OR Bulgaria OR Croatia OR Cyprus OR "Czech Republic" OR Denmark OR Estonia OR Finland OR France OR Germany OR Greece OR Iceland OR Hungary OR Ireland OR Italy OR Latvia OR Lithuania OR Luxembourg OR Liechtenstein OR Malta OR Netherlands OR Norway OR Poland OR Portugal OR Romania OR Slovakia OR Slovenia OR Spain OR Sweden OR Switzerland OR UK OR "Great Britain" OR England OR Scotland OR Wales OR "Northern Ireland")) AND
- PUBYEAR > 2014 AND PUBYEAR < 2026 AND
- (LIMIT-TO (DOCTYPE,"ar")) AND
- (LIMIT-TO (LANGUAGE,"English"))

The search string was used in the Scopus database, retrieving 767 articles. Additionally, after expert recommendations, 23 more articles were added, totalising a sample of 790 articles. After removal of duplicates, these articles were screened by title and abstract, assessing them against a set of inclusion and exclusion criteria.

After the screening and inclusion and exclusion criteria assessment, 152 articles were selected for inclusion in the review. These figures are expressed in the following PRISMA diagram (figure 1).

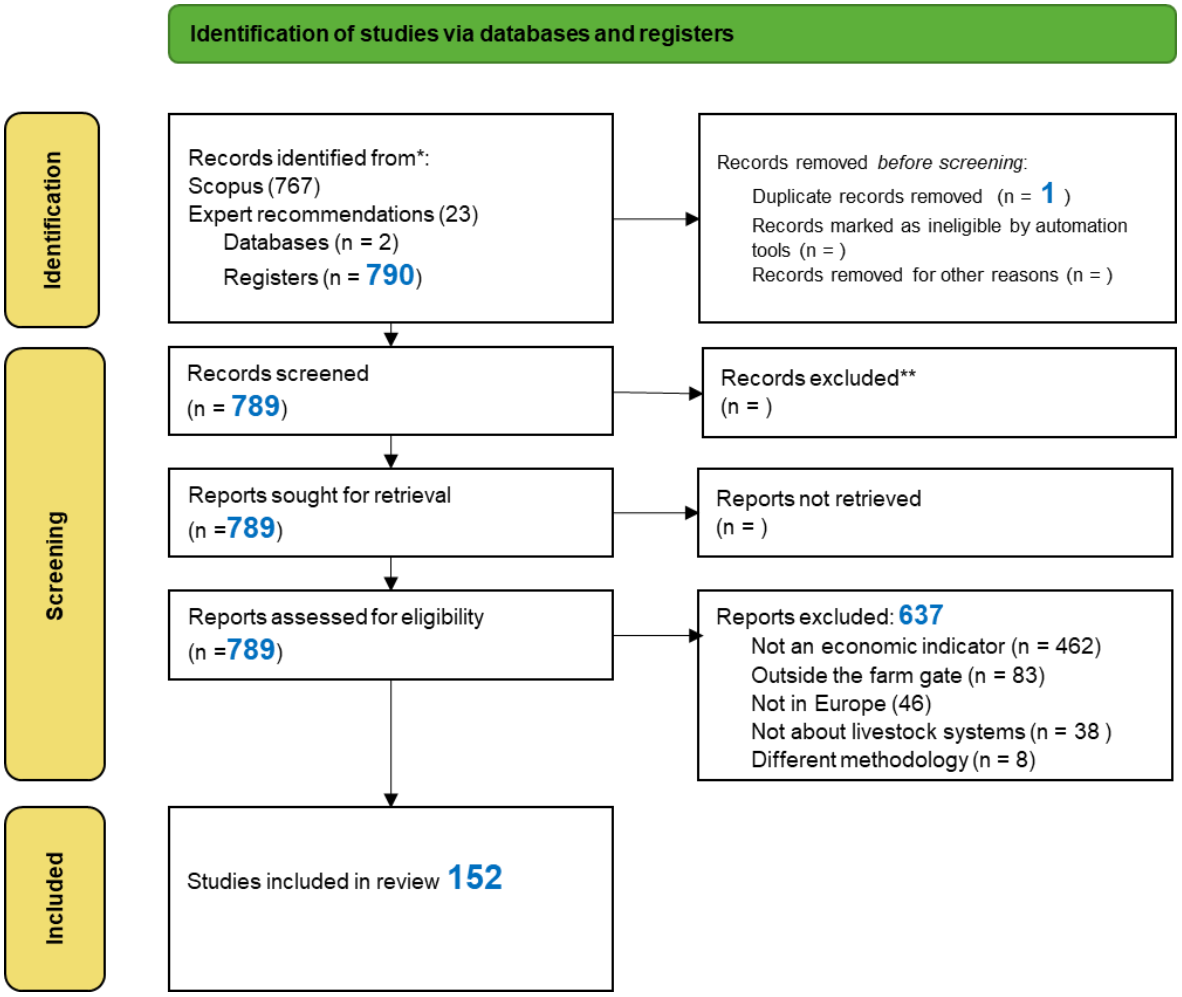


Figure 1: PRISMA diagram for Economic MSS

From this data, further analysis was performed to better understand the information gathered. Particularly, indicators were categorised into different economic objectives. For economics, it was chosen to follow an adapted version of the classification of economic sustainability indicators suggested by Lebacq et al., (2013). This framework was chosen because it was established based on a literature review of livestock production, which is still widely used in scientific literature. According to this framework, economic indicators can be grouped into four different economic objectives and subsequent subthemes. The number of subthemes stated by Lebacq et al., (2013) for each indicator was expanded, looking to describe more

precisely the indicators identified[5]. For example, farm income, farm net income, and farm net profit, net margin or net profit are different indicators names representing farm net income, as defined in the FADN methodology (European Commission, 2020).

The four economic objectives and subsequent subthemes are as follow.

- Profitability, related to the analysis of revenue, costs, and the relationship between them, expressing that relationship either as a difference or as a ratio (Bathaei & Štreimikienė, 2023). Amid profitability, the subthemes are: Income, Costs, Productivity, Efficiency, Price, Investment, Breakeven point, and Management.
- Durability, understood as the ability of a system to perdure, survive, and develop over time. Within durability, the subthemes identified were: Resilience, Liquidity, Solvency, Viability, and Risk.
- Autonomy, referring to systems' dependence on external actors, either on the input or the output side. Two main subthemes: External inputs and subsidies.
- Diversification, defined as the reliance of systems on specific income sources. The only subtheme for this objective is diversification.

2.6.2 TCA

The TCA MSS consists of articles drawn from three online databases, namely Scopus, Web of science and Pubmed. These databases were selected based on their international recognition and their collection of articles concerning various scientific subjects, including externalities originating from livestock farming. The MSS was performed using the "advanced search" feature in the search engines of the selected databases. The article search was performed in September 2024. Table 1 shows the search string used in each database.

The search results from each database were saved in Endnote. Endnote was used to merge search results from different databases. Duplicates were detected and removed using the 'remove duplicate' feature in Endnote. The papers were screened manually. The following steps were followed to select the relevant papers. First, relevant studies were identified based on the title and abstract of the article, which was done by two reviewers independent from each other. In case a paper was classified as excluded, the reviewer should provide a motivation based on the exclusion criteria. Second, the outcomes of the screening by the two reviewers were compared. Third, the outcomes that deviated from each other were screened on whole paper by three reviewers independent from each other. A motivation was provided for each paper. Fourth, the outcomes were compared by the reviewers and the outcomes were discussed. The third reviewer has the final say.

[5] It is important to highlight that the classification was not completely exclusive: i.e., that the same indicator can be used to reflect different themes. In these cases, it was classified into the most coherent category.

The selected papers were equally dividing among two persons for data collection. They worked independently, but meetings were organized to align on data collection. Data collection was done manually. The authors screened the papers and supplementary materials on relevant information.

Database	Search string
Scopus	TITLE-ABS-KEY(("True Cost Accounting" OR "True Price" OR "External Costs" OR "Hidden costs" OR "True Costs" OR "societal costs" OR "damage costs" OR "abatement costs") AND ("Social" OR "health" OR "economic " OR "environmental" OR "ecological " OR "climate") AND ("livestock" OR " dairy cows" OR " beef sucklers" OR "fattening cattle" OR "finishing cattle" OR "sheep dairy" OR "sheep meat" OR "goats" OR " pig" OR " laying hens" OR " broilers" OR " milk" OR "eggs" OR " pork" OR " meat" OR " cheese " OR " mutton" OR " veal" OR " wool" OR " leather" OR "dairy")) AND PUBYEAR > 2009
Web of Science	(TI=(("True Cost Accounting" OR "True Price" OR "External Costs" OR "Hidden costs" OR "True Costs" OR "societal costs" OR "damage costs" OR "abatement costs") AND ("Social" OR "health" OR "economic " OR "environmental" OR "ecological " OR "climate") AND ("livestock" OR " dairy cows" OR " beef sucklers" OR "fattening cattle" OR "finishing cattle" OR "sheep dairy" OR "sheep meat" OR "goats" OR " pig" OR " laying hens" OR " broilers" OR " milk" OR "eggs" OR " pork" OR " meat" OR " cheese " OR " mutton" OR " veal" OR " wool" OR " leather" OR "dairy")) OR (AB=(("True Cost Accounting" OR "True Price" OR "External Costs" OR "Hidden costs" OR "True Costs" OR "societal costs" OR "damage costs" OR "abatement costs") AND ("Social" OR "health" OR "economic " OR "environmental" OR "ecological " OR "climate") AND ("livestock" OR " dairy cows" OR " beef sucklers" OR "fattening cattle" OR "finishing cattle" OR "sheep dairy" OR "sheep meat" OR "goats" OR " pig" OR " laying hens" OR " broilers" OR " milk" OR "eggs" OR " pork" OR " meat" OR " cheese " OR " mutton" OR " veal" OR " wool" OR " leather" OR "dairy")))OR (AK=(("True Cost Accounting" OR "True Price" OR "External Costs" OR "Hidden costs" OR "True Costs" OR "societal costs" OR "damage costs" OR "abatement costs") AND ("Social" OR "health" OR "economic " OR "environmental" OR "ecological " OR "climate") AND ("livestock" OR " dairy cows" OR " beef sucklers" OR "fattening cattle" OR "finishing cattle" OR "sheep dairy" OR "sheep meat" OR "goats" OR " pig" OR " laying hens" OR " broilers" OR " milk" OR "eggs" OR " pork" OR " meat" OR " cheese " OR " mutton" OR " veal" OR " wool" OR " leather" OR "dairy")))) AND PY=(2010-2024)
Pubmed	(("True Cost Accounting" OR "True Price" OR "External Costs" OR "Hidden costs" OR "True Costs" OR "societal costs" OR "damage costs" OR "abatement costs") AND ("Social" OR "health" OR "economic " OR "environmental" OR "ecological " OR "climate") AND ("livestock" OR " dairy cows" OR " beef sucklers" OR "fattening cattle" OR "finishing cattle" OR "sheep dairy" OR "sheep meat" OR "goats" OR " pig" OR " laying hens" OR " broilers" OR " milk" OR "eggs" OR " pork" OR " meat" OR " cheese " OR " mutton" OR " veal" OR " wool" OR " leather" OR "dairy")) AND (2010:2024[pdat])

Table 1: Search string by database (TCA)

An overview of the data items is provided in table 2. Figure 2 illustrates the PRISMA flow diagram. Reasons why records were excluded in first screening: 1) Topic of article not relevant to search question 2) scope of was not Europe or country in Europe.

Table 2: Overview of data items included in the literature review (TCA)

Category	Document information	Scope	Method	Data	Results	Discussion
Data item	Author	System boundary	Indicator (& sub-indicators) for externality	Year of data	External costs value	Difficulties mentioned

	Year	Livestock production systems	Method to quantify externalities	Data quality	External costs unit	
	Title	Product	Model used for calculations	Valuation data sources		
	DOI	Animal species	Valuation method	Monetization factor - value		
	Type of article	Country where case study is applied		Monetization factor – scope		
		Type of externality				
		Externality				

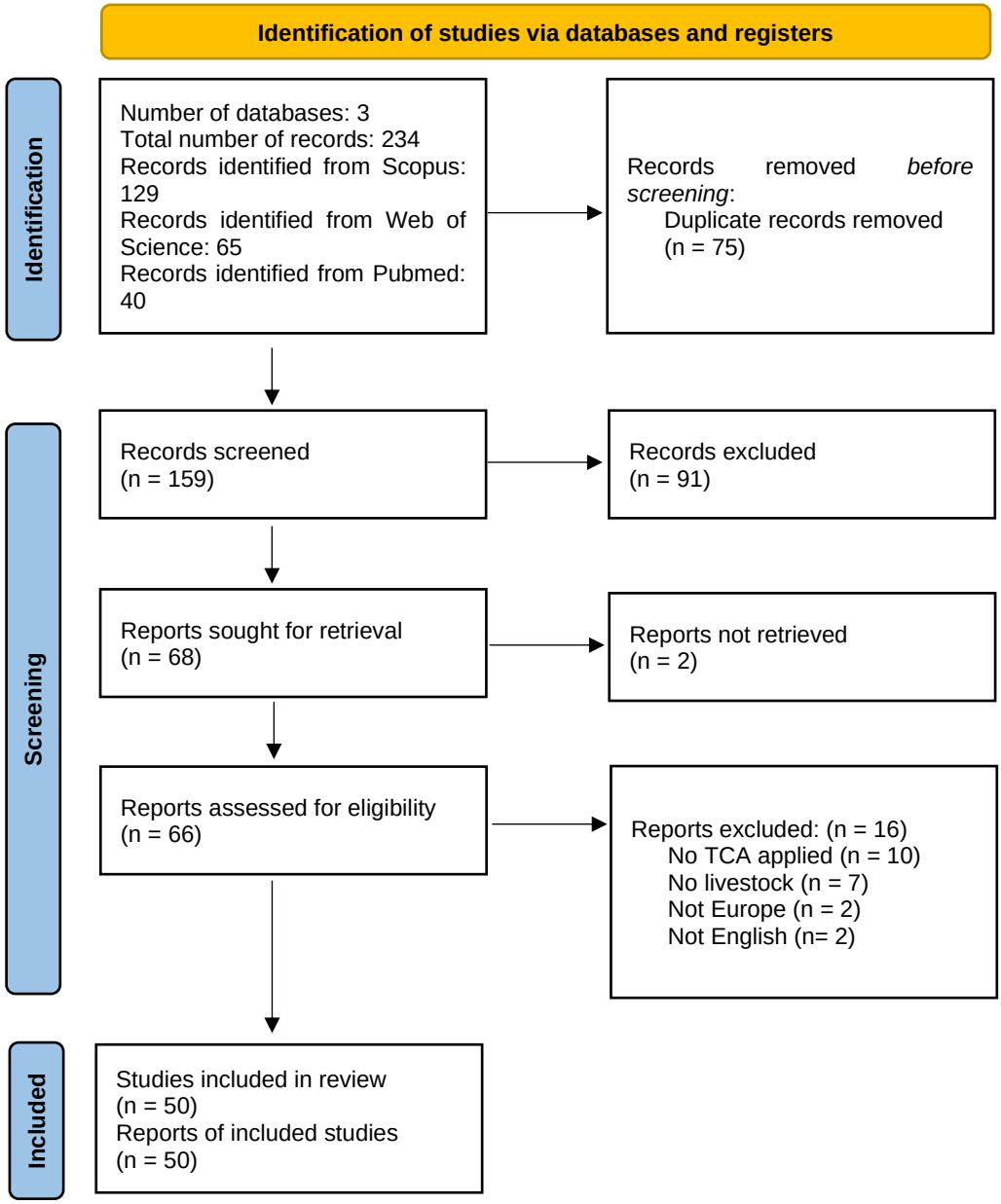


Figure 2: PRISMA diagram for TCA

2.6.3 Social

For the social impact MSS, the databases Scopus, Web of Science, CAB Abstracts, and Google Scholar (table 3) were used. Topic specific search terms included Social LCA, S-LCA, S LCA, Social Life Cycle Assessment, Social impact assessment, or Social assessment. This was combined with search terms for animal types/products and countries in Europe. The title, abstract, and key words where searched – where available in the databases' search engines. Journal articles and conference papers were included. Studies were excluded if they were from before 2000 and not in English. The search was conducted in May 2024. Studies on animal health/welfare without a link to social LCA or social impact assessment were also excluded.

Database	Scopus	Web of Science	CAB Abstracts	Google Scholar
Terms	("Social LCA" OR "S-LCA" OR "S LCA" OR "Social Life Cycle Assessment" OR "Social impact assessment" OR "Social assessment") AND ("Livestock" OR "Beef" OR "Goat" OR "Poultry" OR "Suckler cow" OR "Sheep" OR "Dairy" OR "Cattle" OR "Chicken" OR "Hog" OR "Broiler" OR "Milk" OR "Egg" OR "Pork" OR "Layer" OR "Pig" OR "Piglet" OR "Sow" OR "Calf" OR "Calves" OR "Hen" OR "Mutton" OR "Veal" OR "Steer" OR "Duck" OR "Turkey" OR "Meat" OR "Cheese") AND ("Albania" OR "Andorra" OR "Austria" OR "Belarus" OR "Belgium" OR "Bosnia and Herzegovina" OR "Bulgaria" OR "Croatia" OR "Cyprus" OR "Czech Republic" OR "Denmark" OR "Estonia" OR "Finland" OR "France" OR "Germany" OR "Greece" OR "Holy See" OR "Hungary" OR "Iceland" OR "Ireland" OR "Italy" OR "Latvia" OR "Liechtenstein" OR "Lithuania" OR "Luxembourg" OR "Malta" OR "Moldova" OR "Monaco" OR "Montenegro" OR "Netherlands" OR "North Macedonia" OR "Norway" OR "Poland" OR "Portugal" OR "Romania" OR "San Marino" OR "Serbia" OR "Slovakia" OR "Slovenia" OR "Spain" OR "Sweden" OR "Switzerland" OR "Ukraine" OR "United Kingdom" OR "Europe" OR "EU" or "Russia" OR "European Union")			
Fields	TITLE-ABS-KEY	TI	AB	TITLE-ABS-KEY

Table 3: Search string (search terms and fields) used in the literature review on social impact.

140 records were retrieved, of which twelve were duplicates (figure 3). After screening title and abstract, 83 records were excluded that did not concern social impact of ELP. Assessment of the retrieved 45 reports resulted in further exclusion of 35 reports, because they did not concern social LCA or social impact assessment of European livestock. Two reports were added (one published just after the search start, one was not found with the search string but did include a social impact assessment without mentioning this). Thus, twelve reports were included in the final review.

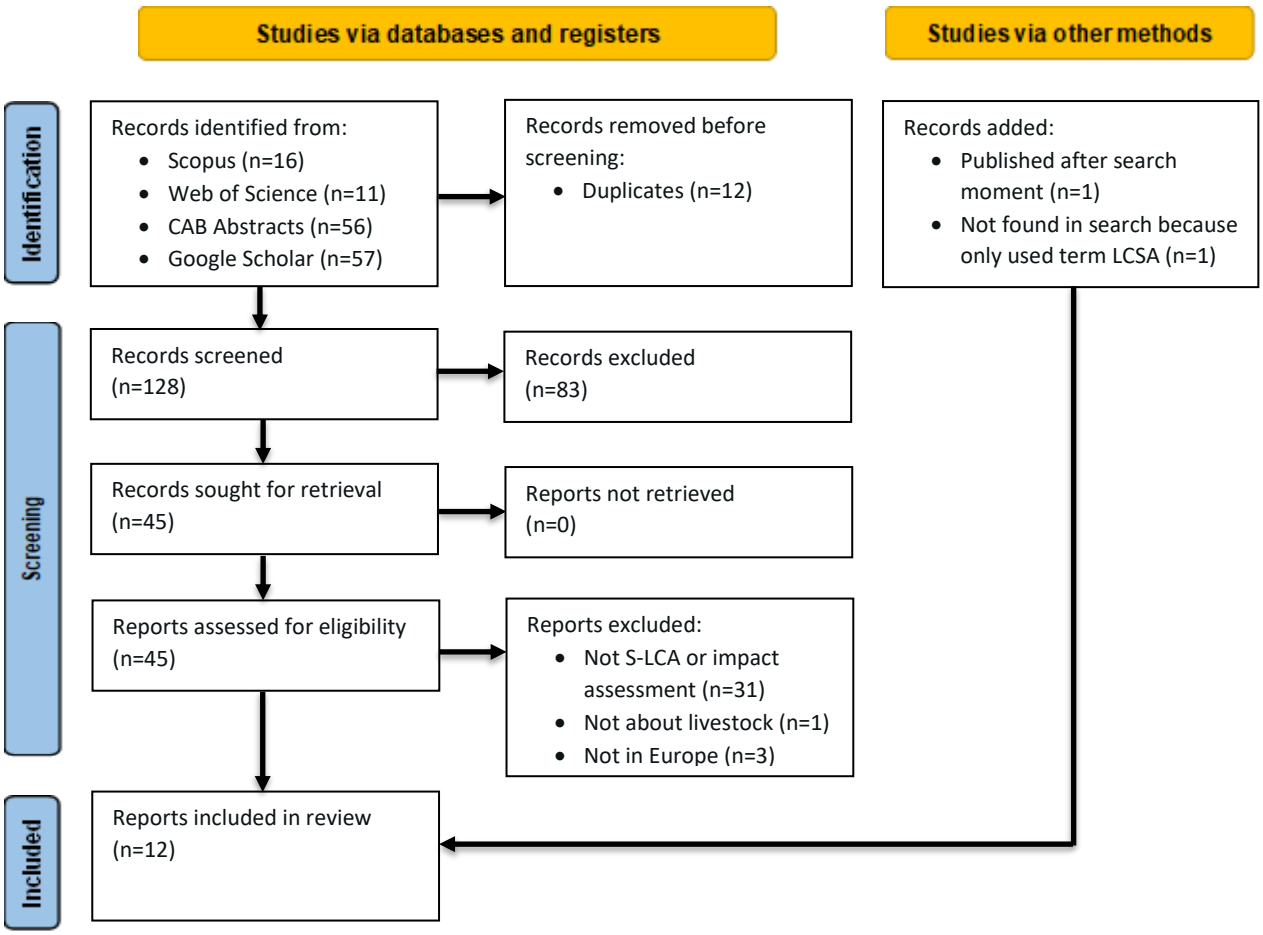


Figure 3: PRISMA diagram for Social MSS

2.6.4 Greenhouse Gases

For the GHG MSS, the Scopus, Web of Science (WoS), and PubMed databases were used. The search encompassed titles, abstracts, and keywords. The selection criteria focused on open-access journals that published research articles in English within the last 10 years. Two searches were conducted separately focusing on the two main sources of direct GHG from livestock systems: i) **enteric methane** (CH4) emissions and CH4 and nitrous oxide (N2O) emissions from **manure management**. For enteric CH4 the initial screening process yielded 2,569 articles, which were then further reduced by introducing in the search keywords such as 'inventory', 'emission factors' and 'prediction' (table 4). Finally, 20 articles were considered (figure 4), which essentially included studies developing emissions factors, models and equations to estimate enteric CH4 either using dataset with individual animals records or data from previous works. For emissions derived from manure management, the initial screening process yielded 1,269 articles, which were then further reduced by introducing in the search keywords such as 'emission factors', 'prediction' and indicators (figure 5). Finally, 9 articles were considered, which essentially included studies developing emissions factors, models and equations to estimate CH4 and N2O either using dataset with individual animals records or data from previous works.

Database	Terms
PubMed *Enteric*	(("enteric"[All Fields] OR "enterically"[All Fields] OR "enterics"[All Fields] OR "enteritis"[MeSH Terms] OR "enteritis"[All Fields] OR "enteritides"[All Fields]) AND ("methanation"[All Fields] OR "methane"[MeSH Terms] OR "methane"[All Fields] OR "methane s"[All Fields] OR "methanes"[All Fields] OR "methanization"[All Fields] OR "methanizer"[All Fields]) AND ("predict"[All Fields] OR "predictabilities"[All Fields] OR "predictability"[All Fields] OR "predictable"[All Fields] OR "predictably"[All Fields] OR "predicted"[All Fields] OR "predicting"[All Fields] OR "prediction"[All Fields] OR "predictions"[All Fields] OR "predictive"[All Fields] OR "predictively"[All Fields] OR "predictiveness"[All Fields] OR "predictives"[All Fields] OR "predictivities"[All Fields] OR "predictivity"[All Fields] OR "predicts"[All Fields]) AND ("cattle"[MeSH Terms] OR "cattle"[All Fields] OR "cattle s"[All Fields] OR "cattles"[All Fields] OR ("sheep"[MeSH Terms] OR "sheep"[All Fields] OR "sheeps"[All Fields] OR "sheep s"[All Fields] OR "sheep, domestic"[MeSH Terms] OR ("sheep"[All Fields] AND "domestic"[All Fields]) OR "domestic sheep"[All Fields]) OR ("goat s"[All Fields] OR "goats"[MeSH Terms] OR "goats"[All Fields]) OR ("buffalo s"[All Fields] OR "buffaloes"[MeSH Terms] OR "buffaloes"[All Fields] OR "buffalo"[All Fields] OR "buffalos"[All Fields]) OR ("swine"[MeSH Terms] OR "swine"[All Fields] OR "pigs"[All Fields]))) AND (y_10[Filter])
PubMed *Manure*	(("manure"[MeSH Terms] OR "manure"[All Fields] OR "manures"[All Fields] OR "manured"[All Fields] OR "manuring"[All Fields]) AND ("manage"[All Fields] OR "managed"[All Fields] OR "management s"[All Fields] OR "managements"[All Fields] OR "manager"[All Fields] OR "manager s"[All Fields] OR "managers"[All Fields] OR "manages"[All Fields] OR "managing"[All Fields] OR "managment"[All Fields] OR "organization and administration"[MeSH Terms] OR ("organization"[All Fields] AND "administration"[All Fields]) OR "organization and administration"[All Fields] OR "management"[All Fields] OR "disease management"[MeSH Terms] OR ("disease"[All Fields] AND "management"[All Fields]) OR "disease management"[All Fields]) AND ("methanation"[All Fields] OR "methane"[MeSH Terms] OR "methane"[All Fields] OR "methane s"[All Fields] OR "methanes"[All Fields] OR "methanization"[All Fields] OR "methanizer"[All Fields]) AND ("emission"[All Fields] OR "emission s"[All Fields] OR "emissions"[All Fields] OR "emissive"[All Fields]) AND ("cattle"[MeSH Terms] OR "cattle"[All Fields] OR "cattle s"[All Fields] OR "cattles"[All Fields] OR ("swine"[MeSH Terms] OR "swine"[All Fields] OR "pigs"[All Fields]))) AND (y_10[Filter])

Table 4: Enteric methane and manure management database search strings.

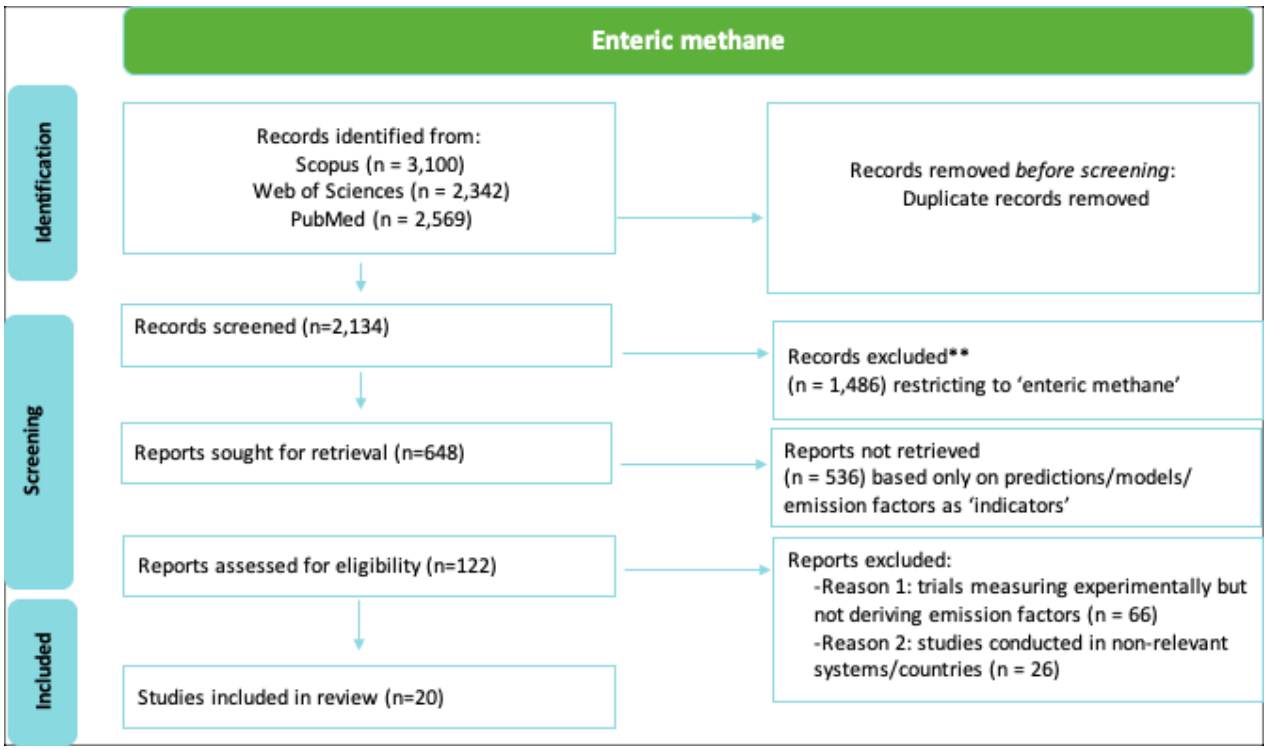


Figure 4: PRISMA diagram for GHG (enteric methane) MSS

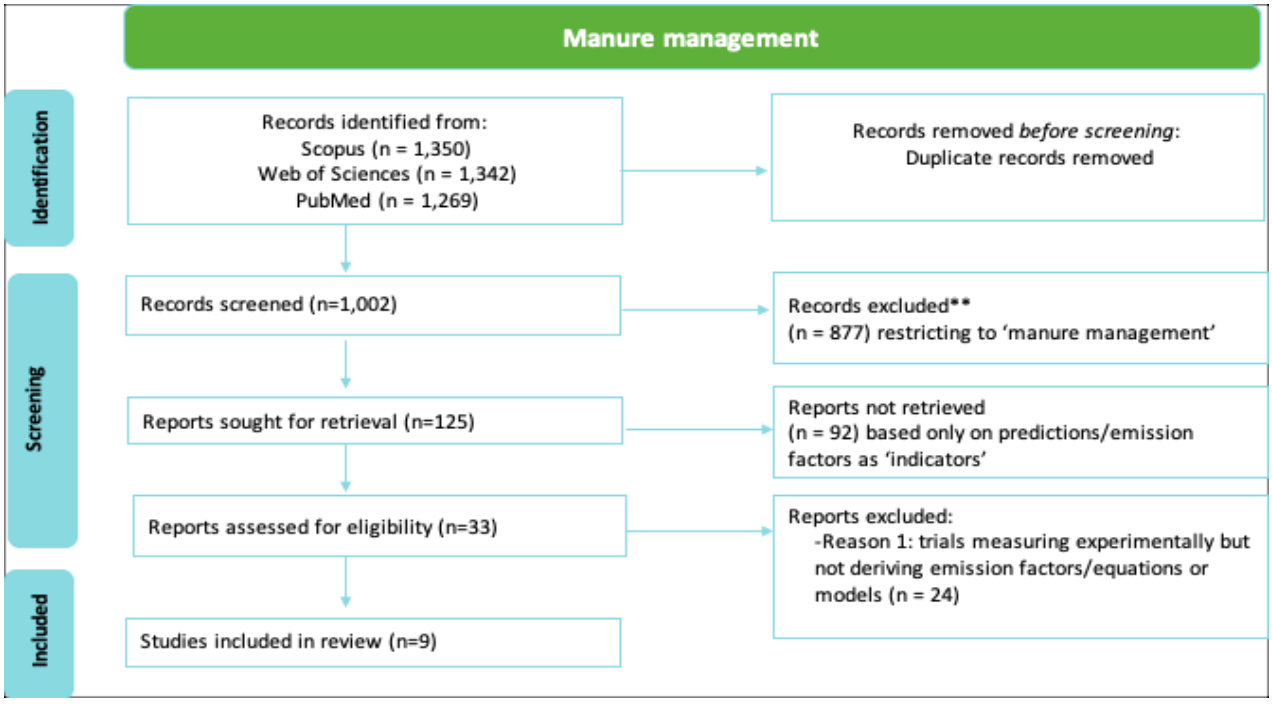


Figure 5: PRISMA diagram for GHG (manure management) MSS

2.6.5 Animal Health & Welfare

For the AHW MSS, Scopus, Web of Science (WoS), and PubMed databases were used. The search encompassed titles, abstracts, and keywords. The selection criteria focused on open-access journals that published research articles in English within the last 10 years. The articles needed to specifically address animal health and/or welfare in ELPs and should have included the terms "indicator" or "iceberg indicator" (see table 5 and figure 6). During the initial screening process, 7,506 articles were identified as potentially relevant, but only 25 met the specified criteria. Further scrutiny led to the exclusion of 6 articles that either did not pertain to animal health and welfare in ELPs or were not classified as research articles.

Database	Terms
Scopus	TITLE-ABS-KEY("Animal Welfare" AND "livestock") AND ("Indicator") AND ("**iceberg"**) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (EXCLUDE (SUBJAREA,"SOCI") OR EXCLUDE (SUBJAREA,"ARTS") OR EXCLUDE (SUBJAREA,"BUSI") OR EXCLUDE (SUBJAREA,"PHYS") OR EXCLUDE (SUBJAREA,"CENG") OR EXCLUDE (SUBJAREA,"MATE") OR EXCLUDE (SUBJAREA,"NEUR") OR EXCLUDE (SUBJAREA,"NURS") OR EXCLUDE (SUBJAREA,"PSYC")) AND (EXCLUDE (DOCTYPE,"cp") OR EXCLUDE (DOCTYPE,"er") OR EXCLUDE (DOCTYPE,"cr") OR EXCLUDE (DOCTYPE,"re") OR EXCLUDE (DOCTYPE,"no") OR EXCLUDE (DOCTYPE,"ch") OR EXCLUDE (DOCTYPE,"le") OR EXCLUDE (DOCTYPE,"ed") OR EXCLUDE (DOCTYPE,"sh") OR EXCLUDE (DOCTYPE,"bk")) AND (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (EXACTKEYWORD,"Animal Welfare"))
Web of Science	(TI=("Welfare") AND AB=("Animal Welfare" AND "livestock" OR "indicator") AND DOP=(2014-01-01/2025-03-01)) AND ((OA==("OPEN ACCESS") AND DT==("ARTICLE") AND LA==("ENGLISH") AND CU==("ENGLAND" OR "GERMANY" OR "ITALY" OR "UK" OR "SCOTLAND" OR "SPAIN" OR "NETHERLANDS" OR "FRANCE" OR "SWEDEN" OR "SWITZERLAND" OR "AUSTRIA" OR "DENMARK" OR "GREECE" OR "POLAND" OR "PORTUGAL" OR "BELGIUM" OR "IRELAND" OR "UNITED KINGDOM" OR "NORWAY" OR "ESTONIA" OR "FINLAND" OR "SLOVENIA" OR "NORTH IRELAND" OR "ROMANIA" OR "CZECH REPUBLIC" OR "SLOVAKIA" OR "WALES")) NOT (SH==("TECHNOLOGY" OR "SOCIAL SCIENCES" OR "PHYSICAL SCIENCES" OR "ARTS HUMANITIES") OR SJ==("INFECTIOUS DISEASES" OR "BIODIVERSITY CONSERVATION" OR "GENETICS HEREDITY" OR "MATHEMATICAL COMPUTATIONAL BIOLOGY" OR "DEVELOPMENTAL BIOLOGY" OR "ENTOMOLOGY" OR "PLANT SCIENCES" OR "REPRODUCTIVE BIOLOGY" OR "RESEARCH EXPERIMENTAL MEDICINE" OR "GASTROENTEROLOGY HEPATOLOGY" OR "LEGAL MEDICINE" OR "MARINE FRESHWATER BIOLOGY" OR "MEDICAL LABORATORY TECHNOLOGY" OR "NEUROSCIENCES NEUROLOGY" OR "PARASITOLOGY" OR "PATHOLOGY" OR "TOXICOLOGY" OR "BIOCHEMISTRY MOLECULAR BIOLOGY" OR "NUTRITION DIETETICS")))
PubMed	(("Animal Welfare" AND "livestock") AND ("indicator" or "iceberg"))

Table 5: Animal Health and Welfare database search string.

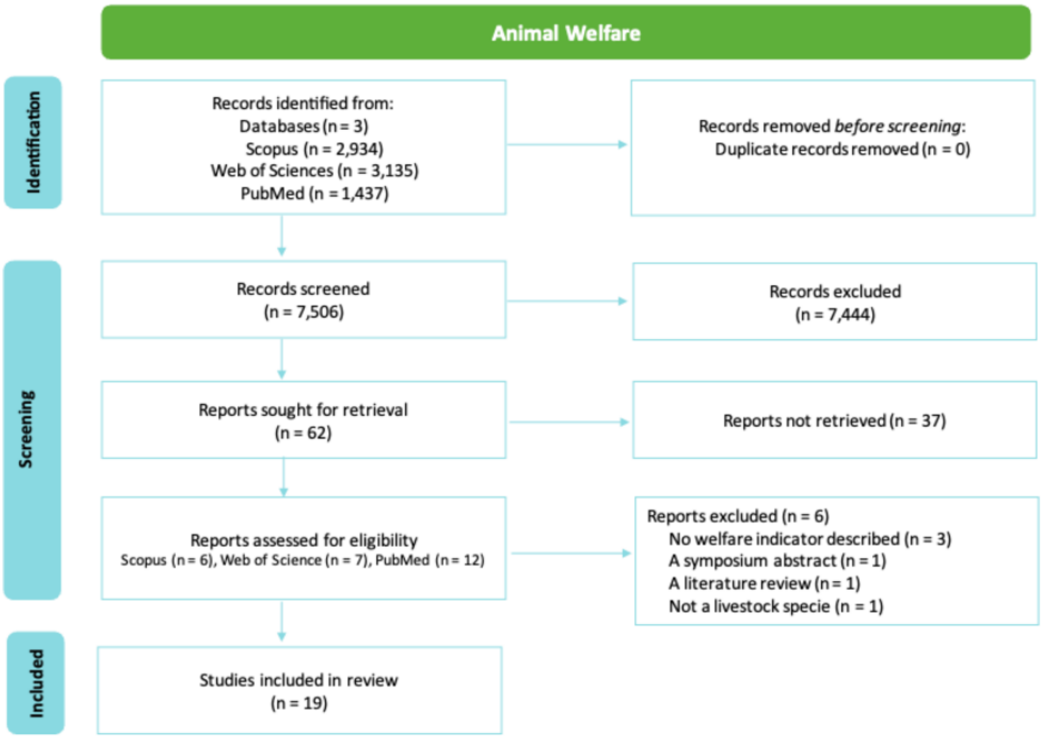


Figure 6: Animal Health and Welfare database search.

2.6.6 Soil Health

The MSS for Soil Health used the databases Scopus, Web of Science, and PubMed (table 6) were used. Topic specific search terms included Soil Health; Soil Quality; Soil Fertility. The MSS included studies meeting the following criteria: (1) published from 2010 onwards in (2) English, (3) peer-reviewed journal articles, (4) data collected from Europe, involving (5) ELPs.

Database	Scopus	Web of Science	PubMed	
Terms	TITLE-ABS-KEY ((soil PRE/2 health) OR (soil PRE/2 quality) OR (soil PRE/2 fertility) AND "dairy cows" OR "beef sucklers" OR cattle OR "sheep dairy" OR "sheep meat" OR lamb OR goats OR pigs OR hens OR broilers OR chickens OR milk OR eggs OR pork OR meat OR cheese OR mutton OR veal OR wool OR leather OR dairy) AND PUBYEAR > 2009 AND PUBYEAR < 2026 AND (LIMIT-TO (AFFILCOUNTRY , "United Kingdom") OR LIMIT-TO (AFFILCOUNTRY , "Italy") OR LIMIT-TO (AFFILCOUNTRY , "France") OR LIMIT-TO (AFFILCOUNTRY , "Netherlands") OR LIMIT-TO (AFFILCOUNTRY , "Poland") OR LIMIT-TO (AFFILCOUNTRY , "Ireland") OR LIMIT-TO (AFFILCOUNTRY , "Belgium") OR LIMIT-TO (AFFILCOUNTRY , "Switzerland") OR LIMIT-TO (AFFILCOUNTRY , "Portugal") OR LIMIT-TO (AFFILCOUNTRY , "Denmark") OR LIMIT-TO (AFFILCOUNTRY , "Czech Republic") OR LIMIT-TO (AFFILCOUNTRY , "Sweden") OR LIMIT-TO (AFFILCOUNTRY , "Undefined") OR LIMIT-TO (AFFILCOUNTRY , "Greece") OR LIMIT-TO (AFFILCOUNTRY , "Austria") OR LIMIT-TO (AFFILCOUNTRY , "Lithuania") OR LIMIT-TO (AFFILCOUNTRY , "Romania") OR LIMIT-TO (AFFILCOUNTRY , "Norway") OR LIMIT-TO (AFFILCOUNTRY , "Finland") OR LIMIT-TO (AFFILCOUNTRY , "Estonia") OR LIMIT-TO (AFFILCOUNTRY , "Cyprus") OR LIMIT-TO (AFFILCOUNTRY , "Croatia") OR LIMIT-TO (AFFILCOUNTRY , "Bulgaria") OR LIMIT-TO (AFFILCOUNTRY , "Slovenia") OR LIMIT-TO (AFFILCOUNTRY , "Hungary") OR LIMIT-TO (AFFILCOUNTRY , "Slovakia")) AND (LIMIT-TO (DOCTYPE , "ar"))			
Fields	TITLE-ABS-KEY	TI	AB	TITLE-ABS-KEY

Table 6: Search string (search terms and fields) used in the literature review on social impact.

Whilst table X outlines the search string of MSS for Soil Health, figure 7 shows the methodology (PRISMA) of the systematic screening of the studies collected for the review. The search strategy identified 1,352 articles with 457 removed due to duplication checks. No additional articles were identified via reference list searching. In total, 895 titles were screened for eligibility followed by 141 for abstract checking. After consultation, 101 papers were chosen for full-text review by both independent reviewers. Any discrepancies between their selections were resolved by a third reviewer, ultimately confirming 78 papers for inclusion in this systematic review.

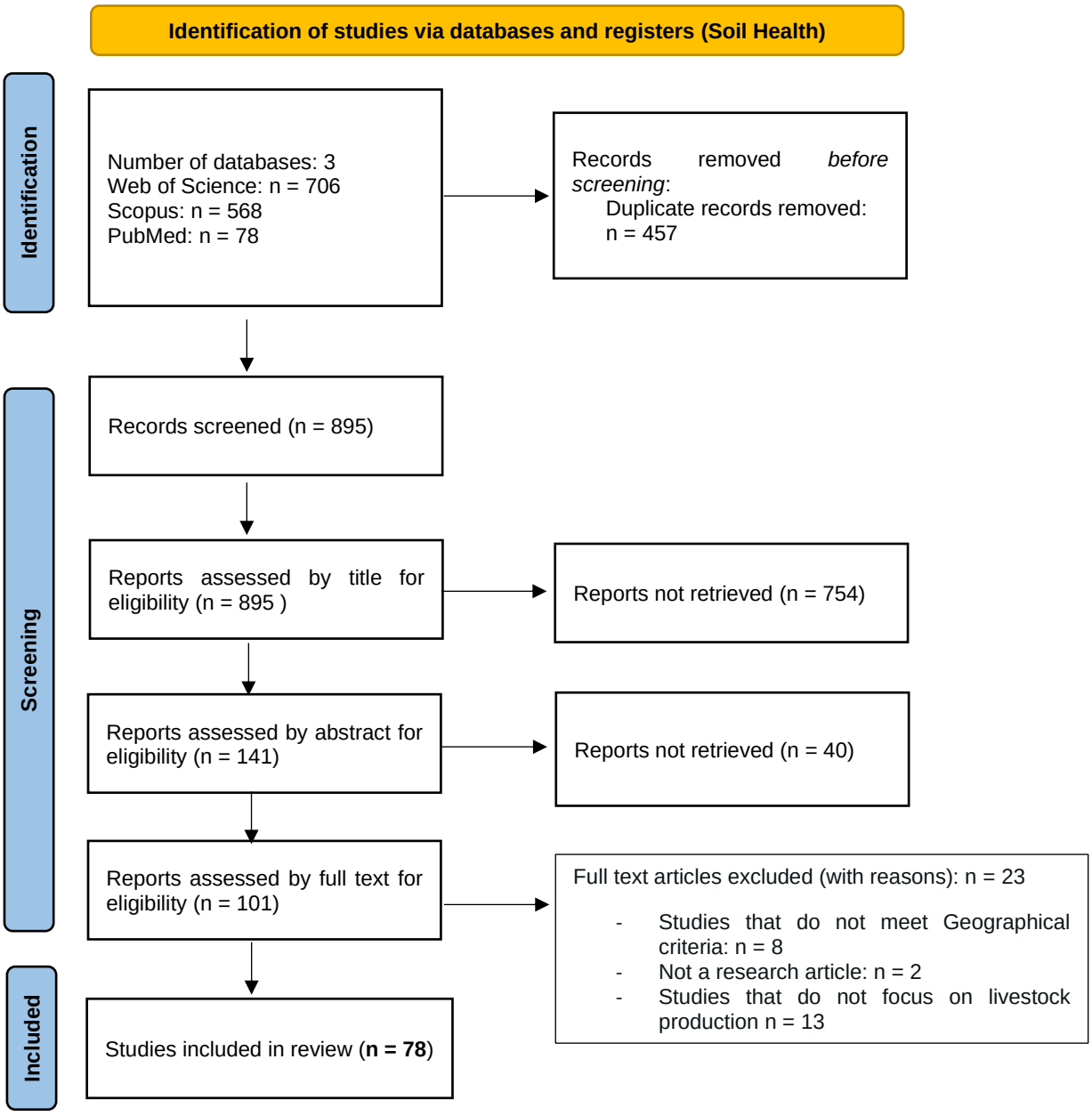


Figure 7: PRISMA diagram for Soil Health MSS

2.6.7 Biodiversity

For the biodiversity MSS, Scopus®, Web of Science®, and PubMed® databases were used to search for and retrieve records of published literature, focusing on the title, abstract and keyword fields to identify studies that assess the impacts—both positive and negative—of ELPs on biodiversity, across different levels of biological organization, from species populations to communities and ecosystems. The literature search was conducted on 18 December 2024 using a search string comprising four main components: (i) terms related to indicator terminology, (ii) terms related to the impact category—which, following test trials, was narrowed down to a single keyword ("biodiversity"), (iii) terms representing livestock species and products, and (iv) terms covering the European territory. The search was restricted to peer-reviewed, open-access research articles published in English between 2015 and 2024. The full search string applied in Scopus is provided below as an example; equivalent versions were adapted for use in the other two databases.

Search string

TITLE-ABS-KEY((indicator OR impact OR metric OR assessment OR index OR benchmark OR performance) AND (biodiversity) AND ("dairy cows" OR "beef sucklers" OR "fattening cattle" OR "finishing cattle" OR cattle OR "sheep dairy" OR "sheep meat" OR sheep OR lamb OR goats OR pigs OR "laying hens" OR broilers OR milk OR eggs OR pork OR meat OR cheese OR mutton OR veal OR wool OR leather OR livestock) AND ("European Union" OR austria OR belgium OR bulgaria OR croatia OR cyprus OR "Czech Republic" OR denmark OR estonia OR finland OR france OR germany OR greece OR iceland OR hungary OR ireland OR italy OR latvia OR lithuania OR luxembourg OR liechtenstein OR malta OR netherlands OR norway OR poland OR portugal OR romania OR slovakia OR slovenia OR spain OR sweden OR switzerland OR "United Kingdom" OR "Great Britain" OR england OR scotland OR wales OR "Northern Ireland")) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (OA,"all")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE,"English"))

A total of 815 records were retrieved from Web of Science (n = 412), Scopus (n = 332), and PubMed (n = 71) (figure 8). After merging the results from all databases and removing 286 duplicates, 529 unique records were retained for title and abstract screening. Of these, 388 records were excluded for not meeting the scope of the review or the inclusion criteria, namely not covering European territory, not assessing livestock impacts or livestock impacts on biodiversity, not measuring or modelling biodiversity[6]. Following this screening stage, 141 studies were selected for full-text assessment. No studies were excluded due to retrieval issues. Full-text assessment led to the exclusion of 45 studies for the following reasons: the study did not cover European territory (n = 2); livestock impacts were not assessed (n = 24); biodiversity was

[6] Among the 388 excluded studies, 25 focused on livestock genetic (breed) diversity. These were not included in the next screening stage or data extraction but were set aside in a dedicated list for potential future use in agrobiodiversity assessments.

neither measured nor modelled (n = 13); biodiversity was used only as an indicator for another purpose (n = 4; e.g., evaluation of the economic value of dung removal by dung beetles (Beynon et al. 2015); or results were duplicated in a study already included in the review list (n=2). Overall, 96 studies were considered eligible and were retained for data extraction.

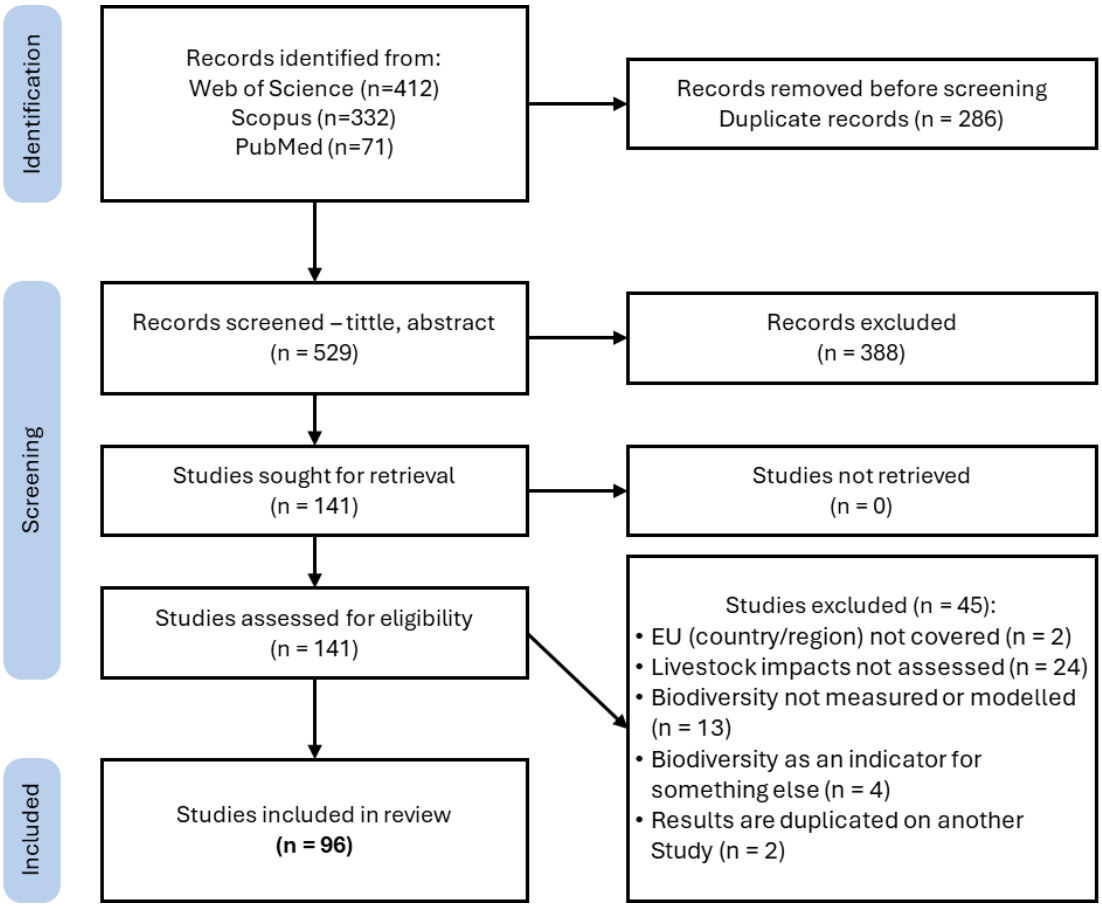


Figure 8: PRISMA diagram for Biodiversity MSS

2.6.8 n-LCA

The MSS for n-LCA used the following academic databases: Scopus, Web of Science, Medline. A comprehensive search strategy (2018–2024) was used to identify all relevant research on whether including nutrition in life cycle assessments (LCAs) of animal source foods (ASFs) influences their position in sustainable healthy diets. Search terms focused on “value of animal source foods” and included “life cycle assessment, nutrition, health or environment” along with terms such as “sustainability”, “nutrition-life-cycle assessment” and “ASF”.

For this systematic review, studies were included if they met the following criteria: published from 2018 onwards in English, peer-reviewed journal articles, data from Europe, involving human populations of all ages and health statuses. Eligible studies discussed ASF consumption in relation to environment, nutrition, or health, incorporating nutrition into LCAs and considering functional units of food e.g., amino acid profile. Studies explicitly addressing the inclusion of nutrition in ASF LCAs and their role in sustainable healthy diets were prioritised. Exclusion criteria encompassed studies focused solely on animal nutrition without human

health implications, exclusively plant- based food studies without ASF comparisons, and traditional LCAs lacking nutritional considerations.

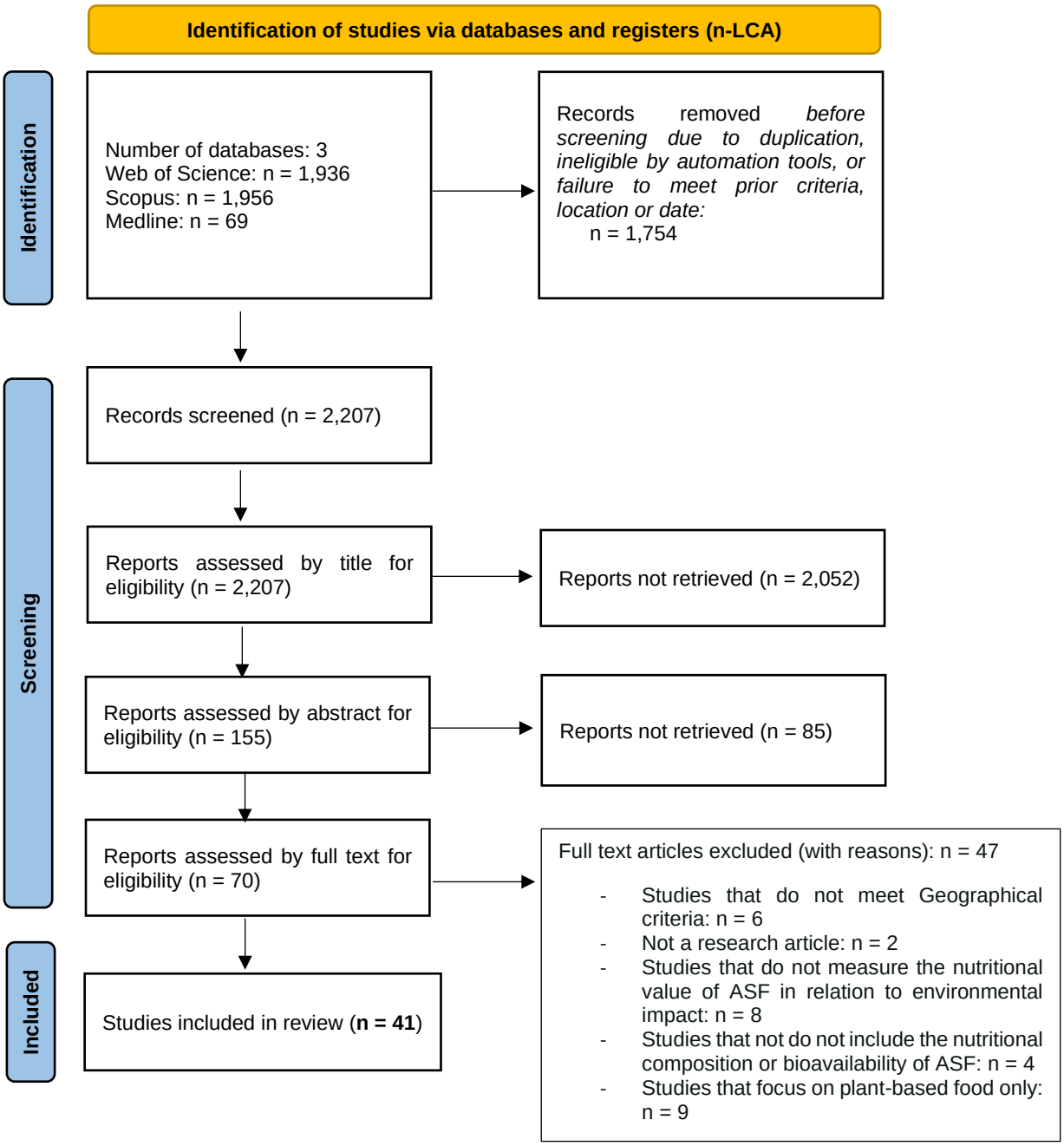


Figure 9: PRISMA diagram for n-LCA MSS

Whilst table 7 outlines the search string of MSS for n-LCA, figure 9 shows the methodology (PRISMA) of the systematic screening of the studies collected for the review. Following deduplication, titles (n = 2207) and abstracts (n = 155) were screened by primary and secondary reviewers. Eligible full texts (n = 70) were independently reviewed (read in full) using inclusion/exclusion criteria, with adjudication by a third reviewer. A total of 41 papers were included.

	Query
Concept 1	"Animal-source foods*" OR "animal products*" OR “animal foods” OR “Animal Proteins” OR “livestock” OR "dairy" OR "beef" OR "cattle" OR "sheep" OR “lamb” OR goats OR pigs OR hens OR broiler* OR Milk OR Eggs OR Pork OR Meat OR Cheese OR Mutton OR Veal OR Wool OR Leather OR “Food products”
Concept 2	Indicator* OR metric* OR theme* OR aspect* OR criteria* OR parameter* OR sub-theme* OR assessment* OR measure* OR index* OR benchmark* OR “Impact*”
Concept 3	“NLCA” OR “n-LCA” OR “Life cycle assessment” OR “Life-cycle assessment”
Concept 4	"Environmental impact*" OR "nutritional value*" OR "nutrient rich food" OR “Carbon footprint" OR "greenhouse gas emissions" or “Global warming potential” OR "Water footprint" OR "land use" OR "Food production" OR "food supply chain*" OR "Sustainable diet" OR "Sustainable food system" or “Food security” OR “Environmental sustainability*” OR “Environmental metrics*” OR “Ecosystem*” OR “Agriculture” OR “Agri-food production” OR “Agri- food systems” OR “Nutrient density*” OR “Nutrition indicators” OR “Food function” OR “Functional unit*”

Table 7: the search string of MSS for n-LCA

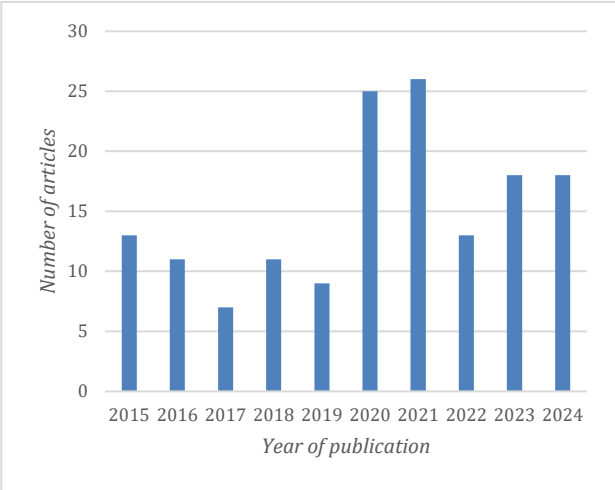
4. Results

This section outlines the results of all (eight) MSS for each respective ICs’. Firstly, emphasis will be placed on summarizing the descriptive statistics of the search results. This may include descriptive/inferential statistics on study demographics/characteristics, for example, publication years, geographical distribution, livestock or species type, management type, and/or system type. This will be followed by outlining the key indicators derived across ICs’, supported with co-efficient(s)/values to address the “three priorities” of this task (indicator; data; impact), to help a discussion narrating the key indicators measuring the positive/negative social, economic, and environmental impact of ELP.

4.1. Economics

The timeline of the 152 articles included in the MSS is reported in figure 10. The figure shows an increasing trend in the number of publications per year between 2015 and 2021, peaking in 2020 and 2021. After 2021, the trend was decreasing, but the number of publications per year remained at higher levels than during 2015-2019 period. Moreover, the research location of published articles, classified by region[7], is presented in figure 11. The figure reveals that research has not been conducted evenly in the different regions. Particularly, Western Europe is the region with most articles (37%). Southern and Northern Europe have conducted similar proportion of articles (24% and 26% respectively), while Eastern Europe is the region with lower number of articles (13%). At the country level, most studies have been focused on France (12%), Italy (10%), Spain (9%), Germany (7%), Ireland (7%), the Netherlands (6%), and the UK (6%).[7]

[7] Each region included the following countries: Northern Europe: Denmark, Estonia, Finland, United Kingdom, Ireland, Latvia, Lithuania, Norway, Sweden. Eastern Europe: Bulgaria, Hungary, Moldova, Ukraine, Poland, Romania, Slovakia, Czech Republic. Southern Europe: Greece, Italy, Croatia, Malta, Portugal, Slovenia, Spain.



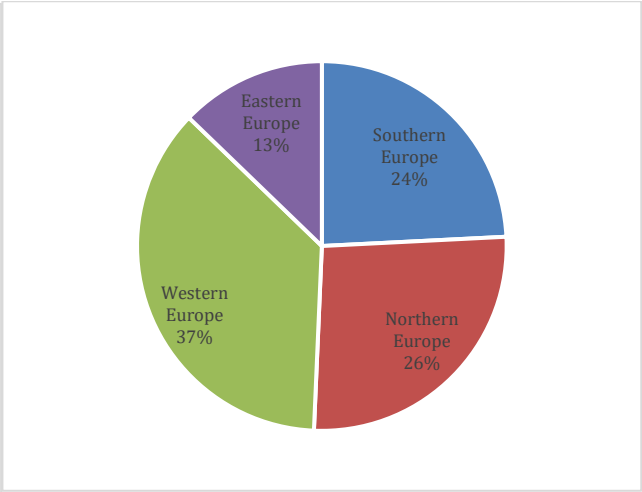


Figure 10: Year of publication of research articles (economics)

Figure 11: Geographical distribution of research articles (economics)

The classification of articles by livestock species is presented in 12. The figure shows that cattle received most of the attention, accounting for 47% of the articles. Among cattle, dairy cattle accounts for 32% of the articles, while 15% focused on beef cattle. Small ruminants represent 29% of the total research (11% for beef sheep, 10% for dairy sheep, and 8% for goats). Finally, monogastric systems account for the remaining 24% of the articles (12% for pigs, 7% for broilers, and 5% for laying hens).

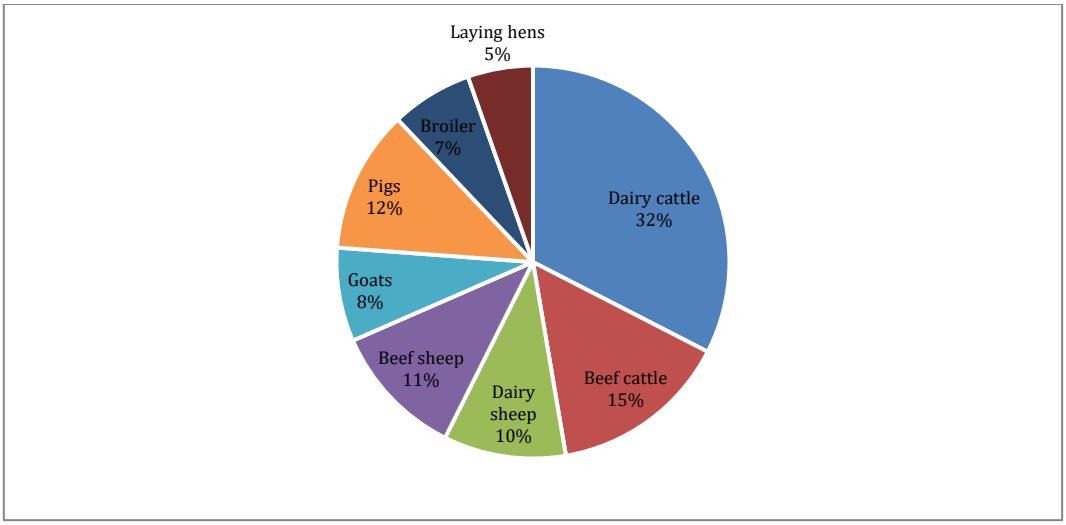


Figure 12: Classification of articles by livestock species

The articles were classified by type of analysis and data utilized (figure 13). The majority (73%) of the articles performed retrospective or ex-post analysis, i.e., they analysed the results of previous data. However, there was an important proportion of articles (27%) that were oriented towards prospective or ex-ante analysis, often related to modelling and projecting the impact of different variables in livestock systems. Additionally, most articles (95%) used quantitative data, while just a minor part of them (5%) were based on qualitative

Western Europe: Belgium, Germany, France, Liechtenstein, Luxembourg, Netherlands, Austria, Switzerland.

data. The latter ones were mainly related to the measure of categories that are complex to reflect with quantitative data, e.g., risk management. Finally, the majority of articles (74%) focuses solely on analysing the economic impact of systems. Nevertheless, 26% of the articles performed a multicriteria analysis, where the economic sustainability dimension was analysed jointly with other sustainability dimensions.

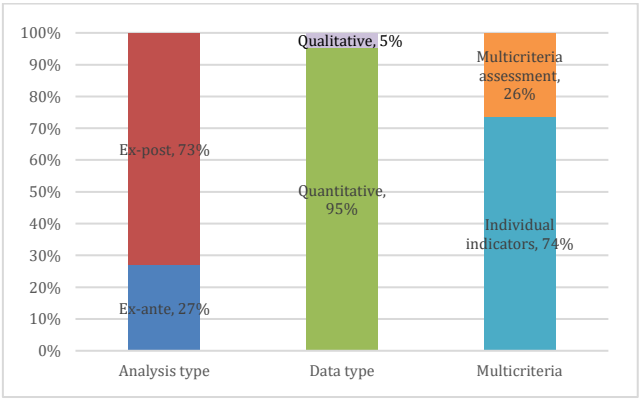


Figure 13: Classification of articles by type of analysis, and type of data

The 152 reviewed articles included a total of 518 economic indicators. These 518 indicators were summarized into 101 'unified indicators'. Following the categorisation process, these 101 'unified indicators' were grouped into 16 subthemes. Finally, the 16 subthemes were grouped into the 4 different economic objectives based on Lebacq et al. (2013)'s framework. The frequencies of each economic objective and subtheme are represented in figure 14. Furthermore, table 8 presents the different indicators identified for each subtheme.

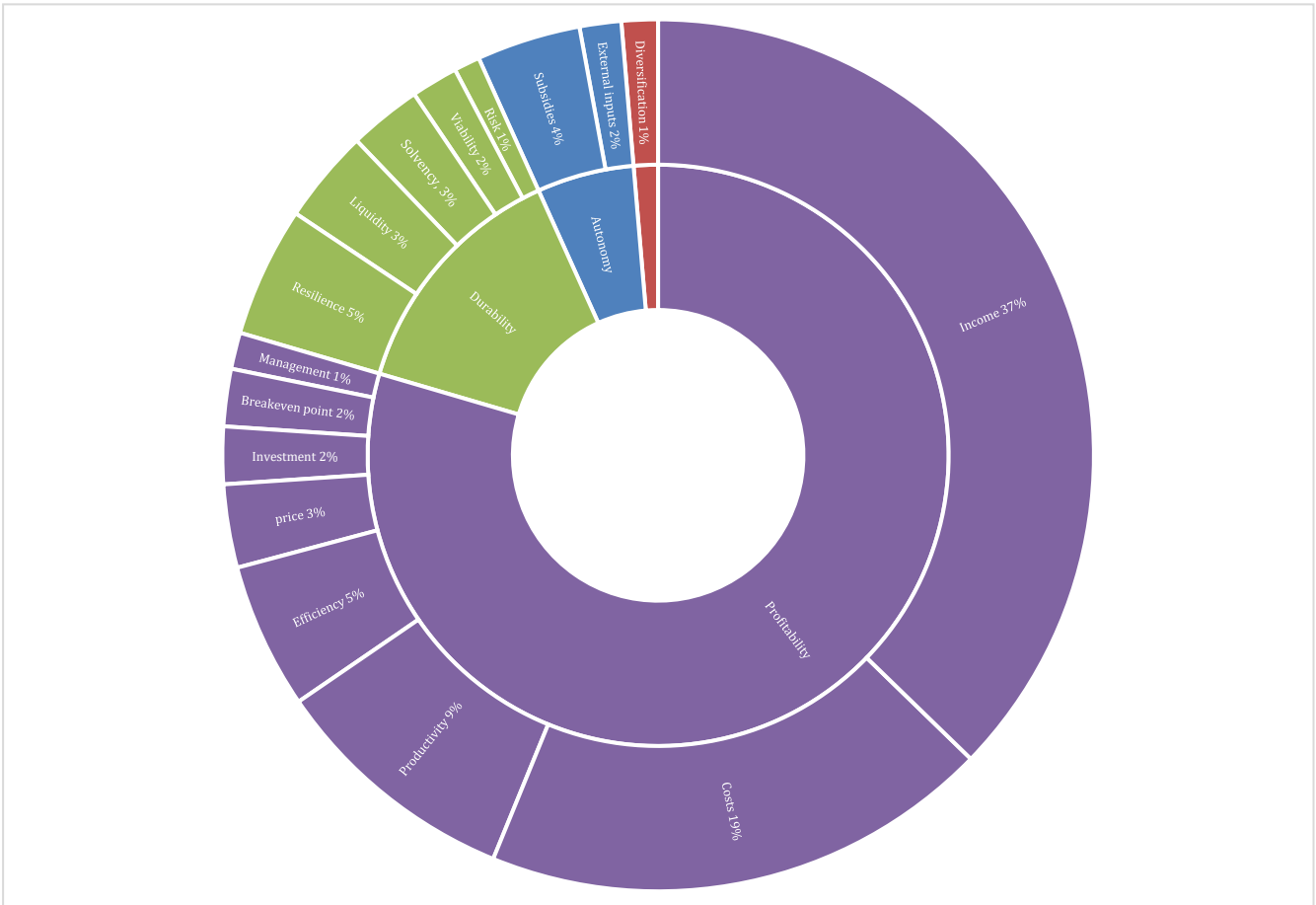


Figure 14: Frequency of indicators by economic objective and subtheme

Table 8: Economic objectives, subthemes, frequencies, Unified Indicators and Identified Indicators

Economic objective	Subtheme	Unified indicators (examples)	Indicators (examples)
Profitability	Income	Gross Margin Income over feed costs Profit	Gross margin, contribution margin Income over feed costs Profitability, total farm profit
	Costs	Feed costs Compliance costs Total costs	Feed purchased costs, Cost of feed per kg of gain Compliance costs Total cash costs, unit cost
	Productivity	Revenue Value of production	Assets turnover ratio Land productivity
	Efficiency	Economic efficiency Technical efficiency	Output to input ratio Technical efficiency (DEA)
	price	Price Milk to feed price ratio	Price premium Milk to feed price ratio
	Breakeven point	Breakeven point Income equal feed costs	Breakeven point of milk price Income equal feed costs
	Investment	Net present value Internal Rate of Return	Value of sow space unit Internal Rate of Return
	Management	Horizontal cooperation Degree of modernity	Horizontal cooperation Degree of modernity
Durability	Resilience	Income variability Resistance to economic shock	Variation coefficient of income with an economic shock Resistance to economic shock
	Liquidity	Liquidity ratio Debt repayment	Quick ratio Level of indebtness
	Solvency	Debt to equity ratio, Assets	Long-term debt-to-equity ratio, Assets to land
	Viability	Viability	Pure permanent viability, Subsidized permanent viability
	Risk	Economic vulnerability, Risk management	Economic vulnerability, Risk management
Autonomy	Subsidies	Subsidies dependence	Dependence on subsidies, Subsidies / Farm net value added
	External inputs	External input dependence, Share of rented land	Reliance on own resources Share of rented land
Diversification	Diversification	Diversification	Sources of income % of income from animal production

Most of the identified indicators (79.5%) belonged to the profitability group. This group contained all the indicators based on the analysis of revenue, costs, and the relationship between them. The most frequent subtheme amid profitability was income (37%), including all the indicators that measure the difference between revenue and costs. The remaining categories were, in order of magnitude: Costs (19%), productivity (9%), efficiency (5%), price (3%), investment (2%), breakeven point (2%), and management (1%). The second economic objective by frequency was durability, with 13.7% of the indicators. The subthemes identified were resilience (5%), liquidity (3%), solvency (3%), viability (2%), and risk, (1%).

The third economic objective was autonomy, with 6% of reviewed indicators. Two main subthemes emerged for this objective: external inputs (4%), and subsidies (2%). Finally, the least represented objective was diversification, with just one subtheme (diversification, 1%).

A chi-square test of independence was performed to evaluate the relation between the livestock sector and the economic objective studied. For increasing the level of observation in the lower categories, broiler and laying hens were grouped into poultry. The relationship between these variables was significant, X^2 (18, N = *989*) = 46.5, p<.01. The results suggest that the livestock sector and economic objective of reviewed indicators are significantly associated. The standardized results, presented in 9, suggest that profitability indicators are used more frequently than expected in the dairy sector. Oppositely, durability indicators were used less frequently than expected in the same sector, and more frequently in Poultry, Pigs, and beef sheep. Autonomy indicators were found more commonly in beef cattle, and less in dairy cattle and poultry sectors. Finally, diversification indicators were infrequent in dairy cattle, while more recurrent in poultry sector. Beef cattle, beef sheep, goats and pigs presented an overall similar tendency, but with a more even distribution, slightly lower than expected for profitability indicators and higher than expected for durability, autonomy, and diversification indicators.

Table 9: Standardized results from Chi-square test of association between livestock sector and economic objective of reviewed indicators

	Profitability	Durability	Autonomy	Diversification
Dairy cattle	2.8	-2.9	-1.5	-1.8
Beef cattle	-1.0	0.4	1.4	0.7
Dairy sheep	0.4	-0.8	0.3	-0.6
Beef sheep	-0.9	1.3	0.2	0.4
Goats	-0.7	0.3	0.8	0.7
Pigs	-1.4	1.5	0.9	0.6
Poultry	-1.2	2.3	-1.1	1.4

Finally, whilst figure 16 illustrates the percentage of reviewed articles and economic output by livestock sector, the units used to express the different indicators can be seen in figure 15. Indicators were frequently used with different units. For example, Farm Net Income was expressed as a total value (Farm Net Income per farm per year), as a value per labour unit (Farm Net Income per Annual Working Unit), per land unit (Farm Net Income per hectare), per livestock unit (Farm Net Income per cow), per output unit (Farm Net Income per kg of Milk), or per output value (Profit Margin).

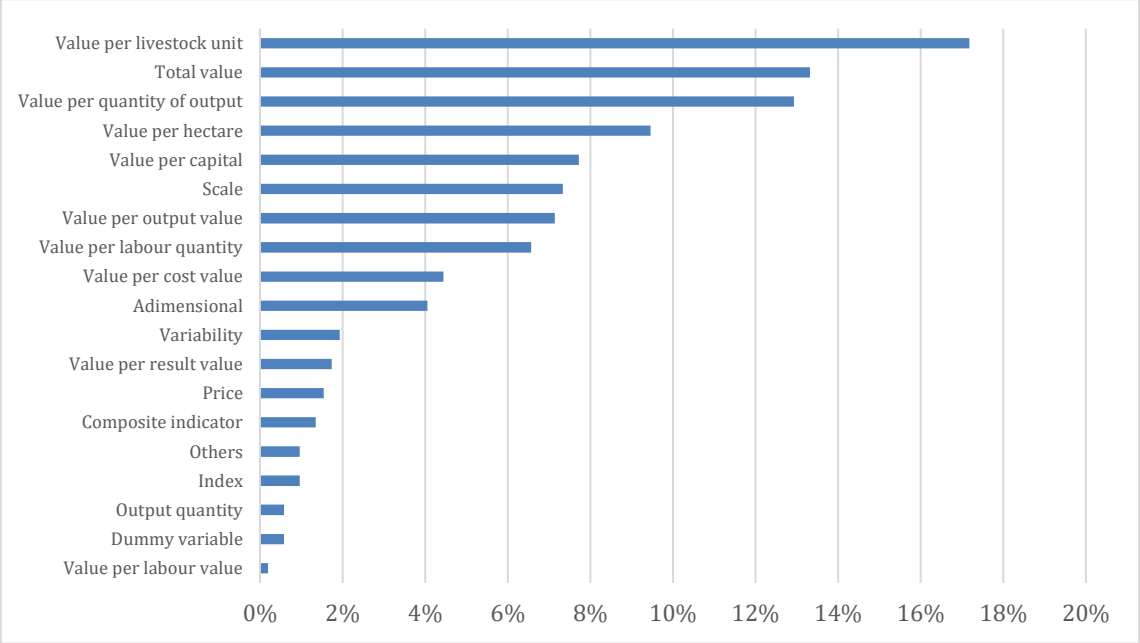


Figure 15: Frequency of type of unit

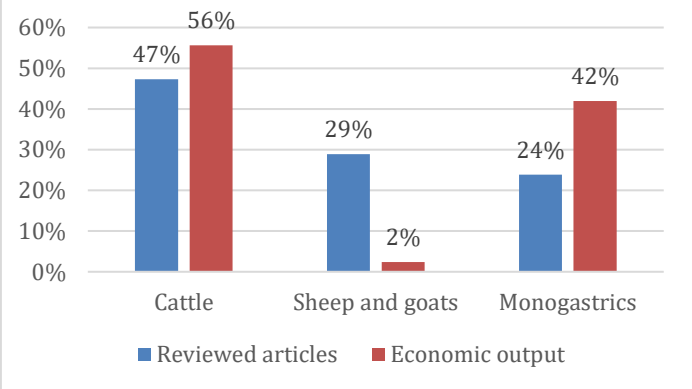


Figure 16: Percentage of reviewed articles and economic output by livestock sector (European Commission, 2025)

4.2. TCA

The 50 identified TCA studies show a diverse picture about the application of TCA to environmental costs and benefits of ELPs, resulting in different types of monetary values measured in a wide range of different units. The number of monetary values estimated per study vary from single value studies with only one estimate to studies in which more than 100 monetary values have been estimated.

Scope

Most of the 50 studies apply TCA at farm level (22), followed by product, region and country (each 8). Only a few studies (4) applied TCA at EU level. For product, most studies included meat (7) and dairy (9) in their analysis, varying from fresh to highly processed products (table 10) .

Scope	*Number of studies*
Product	8
Farm	22
Region	8
Country	8
Group of countries (EU-27)	4
TOTAAL	50

Table 10: Scope in 50 identified TCA studies

Germany (or only certain federal states) was considered in most articles (13 out of 50). Four out of 50 studies considered the EU-27 in their analysis. This was followed by the Netherlands, Denmark and Ireland (each 4 out of 50). France, Italy and Belgium each 3 out of 50. In most studies, the system boundary was farm-to-farm gate (22 out of 50 studies). 15 studies use cradle-to-farm gate as system boundary. Five studies use cradle-to-consumer gate as system boundary. The following system boundaries are applied in only one study each: cradle-to-factory gate, cradle-to-grave, cradle-to-supermarket gate. In a few studies (3), the system boundary was not specified. The number of studies that were published increased after 2019. Most studies have been published in 2020 and 2023 (8 each). Most studies that were published before 2017 had a cradle-to-farm gate or farm-to-farm gate approach. All studies that had a cradle-to-supermarket-gate or cradle-to-factory gate approach, were published in 2020 or later.

Animal species

Most of the 50 TCA studies consider multiple animal species in their analysis (29 out of 50), while the remaining studies focus on only one specie (21 out of 50). Dairy cattle is the most assessed animal species (32 out of 50), followed by beef cattle (14 out of 50), pigs (20 out of 50), poultry (10 out of 50) and sheep en goat (2 out of 50 each). Some studies assessed the whole agricultural or livestock sector and did not specify the animal species under consideration (9 out of 50) (figure 17).

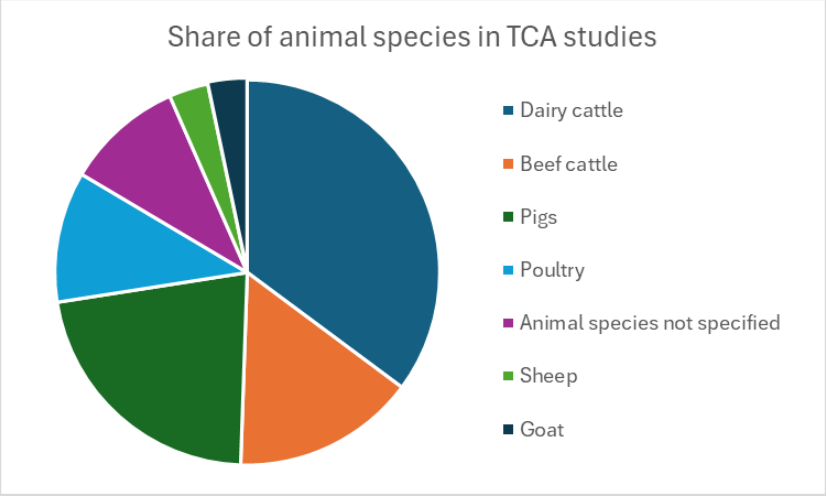


Figure 17: Distribution of animal species in TCA studies

Externalities

In the 50 identified TCA studies we distinguish social and environmental externalities. Nearly all studies (47 out of 50) consider only environmental externalities, while 2 out of 50 studies consider only social externalities – one study considers both. Regarding the environmental externalities, climate change is considered by most studies (22 out of 50), followed by acidification (17 out of 50) and eutrophication (13 out of 50). Biodiversity and ecosystems are assessed in only two studies (table 11).

Table 11: Environmental externalities and indicators considered in the 50 TCA studies

Theme / externality	Number of articles	Indicators
Acidification (air pollution and eutrophication)	13	• SO_2-equivalent • NH_3 emissions • N-surplus
Air pollution (NOx emissions/NH_3 emissions)	6	• NOx-emission • Yoll • DALY
Particulate matter formation	6	• Kg PM2.5 equivalent • Kg PM10 equivalent
Ecotoxicity	3	• CTUe (Comparative toxic units) • 1,4 DB-equivalent
Eutrophication	15	• Kg P eq. • kg PO_4-equivalent • Kg N-equivalent • P surplus (on farm level) • % P-reduction
Water use	3	• M^3 water extracted
Biodiversity	2	• M^2 tropical forest converted to cropland • PDF (Potentially Disappeared Fraction of species)
Ecosystems	2	• NH_3-emissions to air • NOx emissions • N runoff • Kg N to surface water
Photochemical ozone formation	3	• NOx-equivalent • Kg NMVOC (non-methane volatile organic compounds)
Ozone depletion	2	• Kg CFC-11 equivalent
Ionising radiation	2	• kBq U235-equivalent
Climate change	22	• CO_2-equivalent
Ionising radiation	2	• Kbq U235-equivalent
Land use	4	• M^2a
Human toxicity	4	• Kg 1,4-DB equivalent • CTUh • Kg C_2H_3Cl-equivalent (Vinyl Chloride)
Non-renewable resource depletion	3	• Kg oil • MJ • kg Sb-equivalent (Sb=Antimony)

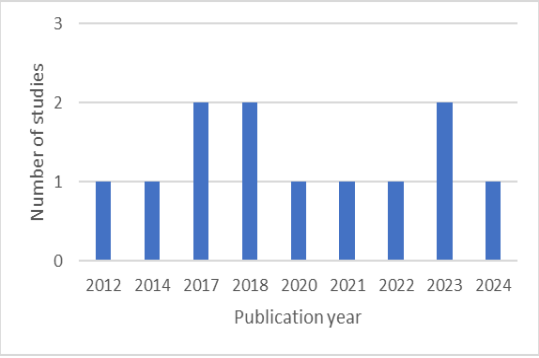
Looking at the top 3 externalities, climate change is in most cases addressed in combination with dairy cattle, followed by pigs, beef cattle and poultry (table 12). The externalities acidification and eutrophication closely addressed in combination with the four different animal species.

Table 12: Externalities considered per animal species

Rank	Dairy cattle		Pigs		Poultry		Beef cattle	
	Externality	**# studies**	**Externality**	**# studies**	**Externality**	**# studies**	**Externality**	**# studies**
1	Climate change	22	Climate change, acidification	10	Climate change	6	Climate change	8
2	Acidification	6	Eutrophication	5	Acidification	4	Acidificiation	4
3	Eutrophication	3	Human toxicity	4	Euthropication	3	Ecotoxicity, Human toxicity, Land use, Eutrophication	3
Total # of articles		32		20		10		14

4.3. Social

Of the twelve reports available on social impact of ELP, ten were peer-reviewed articles and two conference proceedings. They averaged on one study per year since 2012 (figure 18) These studies addressed the most common farmed animal types, with one study addressing seven animal types, two studies five animal types, and nine studies one animal type (figure 19). Eight studies addressed the conventional production system, two studies both conventional and organic, and three studies did not specify the production system (one study did not specify for horses but did for the other animal types) (figure 20). The studies concerned a wide range of European countries, but each country was only covered by a maximum of two studies (figure 21). The ten peer-reviewed studies presented quantitative results, whereas the two conference proceedings only presented impact subcategories and/or indicators to be used in a social impact assessment.



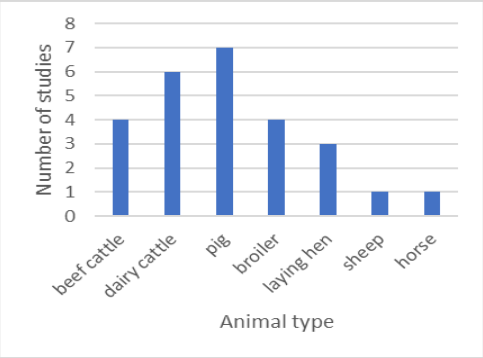
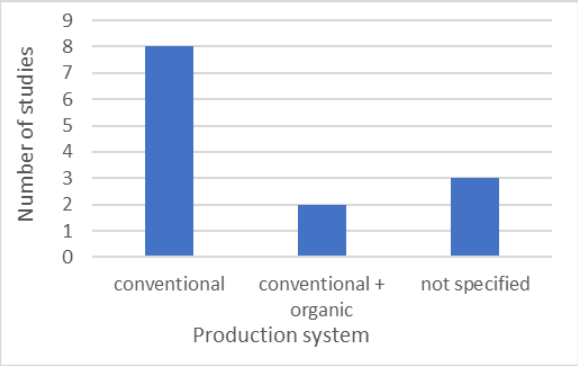


Figure 18: Year of publication (Social)

Figure 19: Species type (Social)



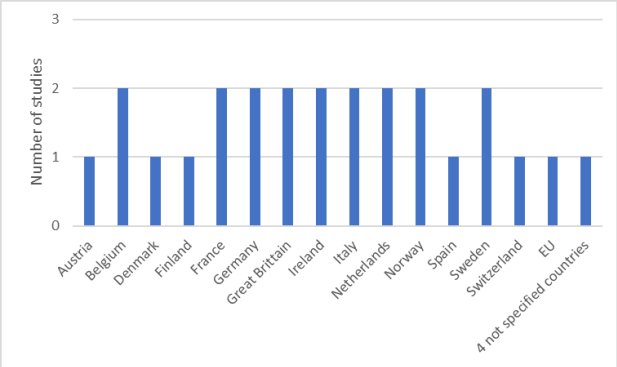


Figure 20: Production system for Social MSS

Figure 21: Geographical distribution (Social)

All the stakeholder categories from the UNEP guidelines (UNEP, 2020) were addressed in the studies, although to a different extent (figure 22). The stakeholder categories worker and local community were addressed most, and the category children least. Some studies defined animals as a separate category, whereas others included it in society. Figure 22 also shows that there is a wide range of impact subcategories addressed in the studies. Of all impact subcategories, 72 were used in only one study and 18 in two or three studies. Only the impact subcategories local employment and fair salary were addressed in four studies and health and safety (workers) in eight. Many of the impact subcategories were similar to the ones defined in the UNEP guidelines (UNEP, 2020), however also other impact subcategories were presented (such as affordability, eating quality, age structure, young labour). Studies sometimes used the same or similarly named impact subcategories (e.g., animal health and animal welfare, working hours and working time, fair wage and fair salary), but generally these were measured with different indicators, thus capturing a different aspect of the concept. Three studies addressed only one impact subcategory (all related to animal welfare/health), one study two (health and safety of workers, human health/nutrition), and the other studies between nine and 27 impact subcategories.

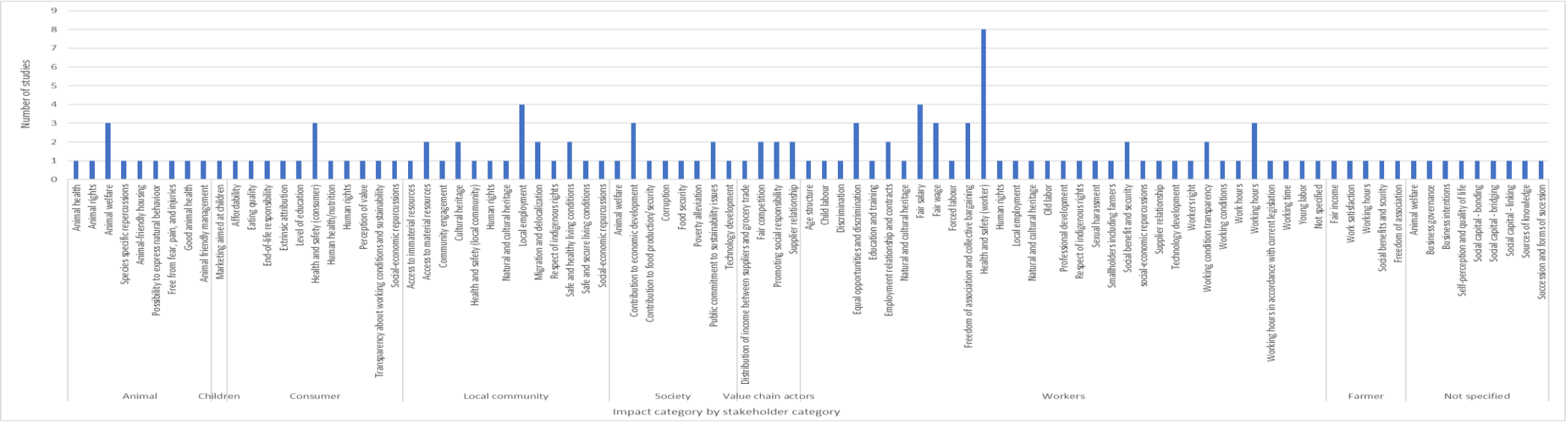


Figure 22: Stakeholder category and impact subcategories addressed within social MSS.

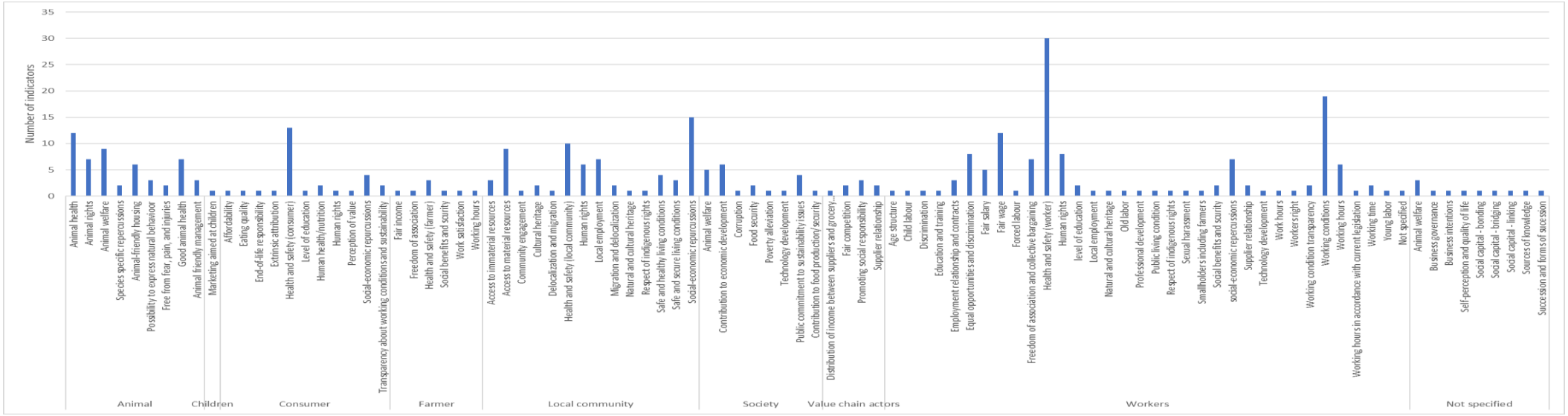


Figure 23: Number of indicators used by stakeholder category and impact subcategories as addressed in literature on the social impact of ELP

Between one and thirty indicators were used to measure each impact subcategory (figure 23). In total, 49 impact subcategories were measured using one indicator, fourteen using two, and eight using three indicators. A wide range of indicators was used to measure one impact subcategory, each study using different ones. Data availability seemed to be the driving factor for selecting indicators, rather than aligning with other studies.

Ten of the twelve studies, the journal articles, provided quantitative results of social impact, whereas two studies, the conference proceedings, focused on methodology development without providing quantitative results. Out of the ten studies that provided quantitative results, eight quantified social impact of a livestock production system, of which three also included environmental/economic impacts (conducting a Life Cycle Sustainability Assessment), and two only quantified animal welfare impacts. Out of the studies that performed a quantitative social impact assessment, most studies used secondary data (e.g., statistics), one study used the PSILCA database, and two studies used primary data (e.g. collected on farms/via interviews). Only two studies addressed the implications of data quality, uncertainty, or model assumptions, despite their potential influence on results.

Six studies used the Reference Scale (RS) approach and one study used both the RS and Impact Pathway (IP) approach. The IP approach was used for the indicators fatality rate, working time, and cost of environmental impact on human health.

Ten studies used weighting to aggregate lower-level results into a higher level (inventory indicators into indicators, indicators into impact subcategories, impact subcategories into social impact). Five studies used weighting of multiple inventory indicators into an indicator, eight studies weighting multiple indicators into an impact subcategory, and one study multiple impact subcategories into social impact. Three weighting methods were used: equal weights (average, sum), unequal weights based on experts or activity variables, and complex formulas (for animal welfare). Some studies used multiple weighting methods at multiple levels.

4.4. Greenhouse Gases

3.4.1 Enteric CH_4

The 20 articles selected can be divided into (1) Tier 2 emissions factors as equations from a data set of individual animal records (2,566 in dairy cattle -Niu et al., 2017-, 2,005 in beef cattle -Van Lingen et al., 2019- and 2,973 in sheep -Belanche et al., 2023) (figure 24) or (2) those that obtained equations using already published studies, in total 543 treatment means from 145 studies.

In total, considering both types of studies, 183 different prediction equations have been registered, 39% for dairy cattle, 20 % for beef cattle, 3% for both dairy and beef combined and 36% for sheep (figure 24).

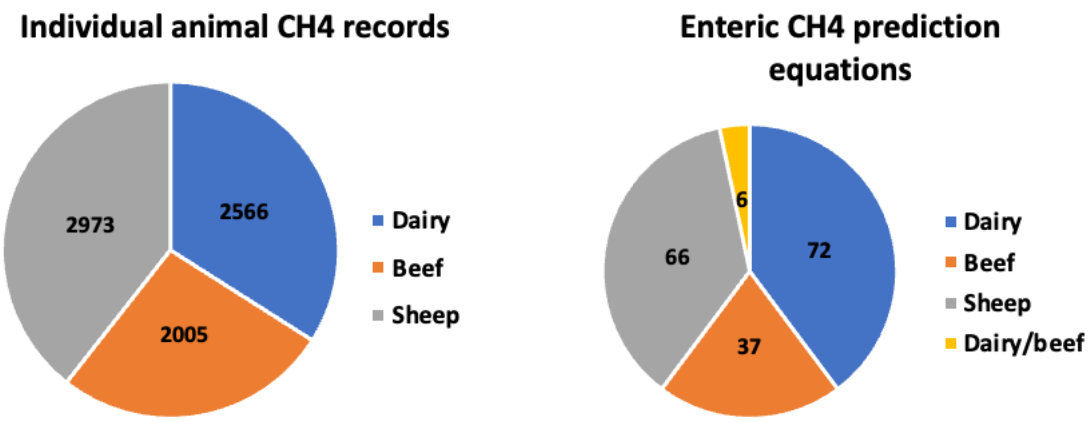


Figure 24: Details on database used for enteric methane review

The prediction equations consisted of mixed linear models. Overall most works used a sequential approach by incrementally adding key variables to develop models with increasing complexity. Methane emissions were predicted by fitting linear mixed models. The equations were developed for different subsets within each animal category as follows:

- **Dairy cattle**:
  - Regional specific subsets: Intercontinental, EU and USA
- **Beef cattle:**
  - Regional specific subsets: North America and EU
  - Diet specific subsets: ≥25% and ≤18% dietary forage contents
- **Sheep:**
  - Age specific subsets: young sheep (<1-year-old) and adult sheep (>1-year-old)
  - Diet specific subsets: 100 % forage and forage: concentrate (mixed) diets
  - Climate specific subsets: temperate and warm climates

A range of different variables related to feeding and nutrition were used to develop the models, dry matter intake (DMI) being the main one. Less complex models requiring only DMI had predictive ability comparable to complex models, although the inclusion of diet characteristics improved the predictive capacity, especially with neutral detergent fibre (NDF), ether extract (EE) and ash, with variable impact depending on the animal categories.

3.4.2 Manure management

Although the search approach yielded 9 studies, which are described in the annex excel file, this review will mostly focus on the work conducted as part of the project DATAMAN (Hassouna et al., 2022): The international project DATAMAN (http://www.dataman.co.nz) aims to develop a global database on greenhouse gases (N2O, CH4) and NH3 emissions from the manure management chain to refine EFs for

national GHG and NH3 inventories. To develop this database, Data collection was carried out by partners of the MELS (Mitigating Emissions from Livestock Systems; https://www.mels-project.eu/) and DATAMAN (http://www.dataman.co.nz; link to the project's database) consortia from September 2018 to May 2021. Information on CH4, N2O, and NH3 emissions from animal housing (cattle, swine, and poultry) and outdoor manure storage was sourced from published peer-reviewed research, theses (undergraduate and postgraduate), and conference papers.

Data collation covered 24 countries for animal housing and 20 for storage. In addition to data collected from peer-reviewed research, the database includes information extracted from existing datasets, such as ELFE (ELevage et Facteurs d'Emission; Vigan et al., 2019), data collated in connection with the 2019 refinement of the 2006 IPCC guidelines (IPCC, 2019), reviews (e.g., Kupper et al., 2020), and many individual studies not captured in reviews or existing datasets. Relevant information for different animal categories, manure types, livestock buildings, outdoor storage, and climatic conditions was collated from published peer reviewed research, conference papers, and existing databases published between 1995 and 2021. In the housing database, 2024 EFs were collated (63% for NH3, 19.5% for CH4, and 17.5% for N2O). The storage database contains 654 NH3 EFs from 16 countries, 243 CH4 EFs from 13 countries, and 421 N2O EFs from 17 countries. Across all gases, dairy cattle and swine production in temperate climate zones are the most represented animal and climate categories.

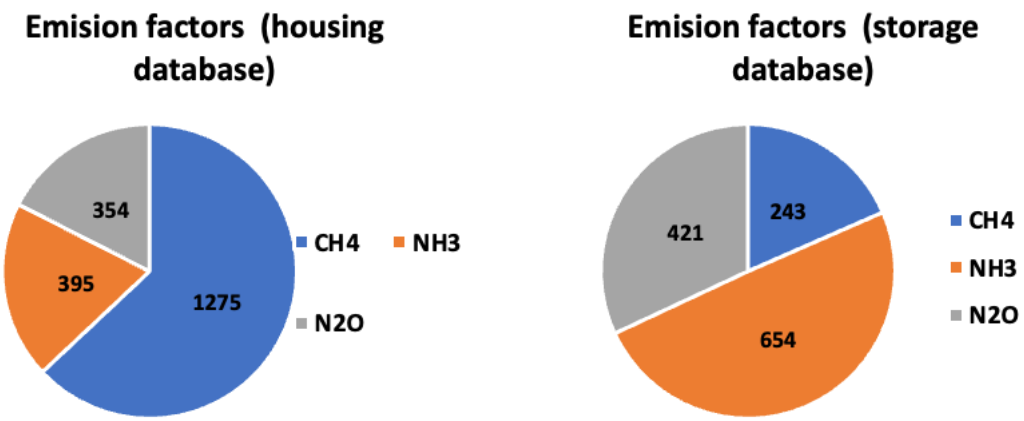


Figure 25: Details on database used for manure management associated emissions review

4.5. Animal Health & Welfare

The selection criteria for this research focused on articles published within the last 10 years; however, 90% of the articles retrieved were from the last 5 years (specifically, 2019 to 2024). This search yielded AHW indicators descriptions across various production systems in 15 countries (figure 26). While the primary focus was on animal health and welfare in ELPs, two relevant research articles from outside Europe (specifically from Argentina and the U.S.A.) were also included in the final list due to their significant contributions.

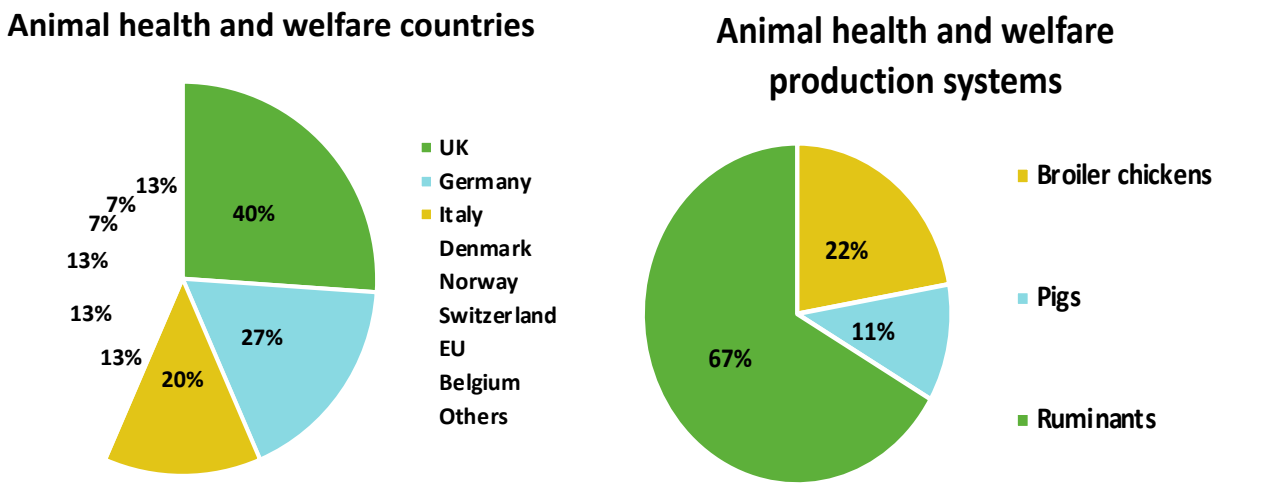


Figure 26: Countries and livestock production system obtained in the animal health and welfare indicators literature review

From the literature review, 100 indicators were identified, with 57% classified as animal-based and 43% as resource-based. Some indicators were common across various livestock production systems (table 13); for instance, lameness and body condition score emerged as the two most prevalent indicators. There were discrepancies in the feasibility of measuring these indicators across different production systems, leading to their categorization into low, medium, or high applicability (figure 27). The indicators were further classified as quantitative (n = 27) or qualitative (n = 73). Their coefficient outputs were represented as binary (e.g., no pain vs. pain) or multinary scores (e.g., normal feces, soft feces, and diarrhea), and measurement units (e.g., kg, L, %, minutes, respiration per minute, etc.). The indicators for AHW could be grouped into two main topics: comfort and health. Comfort indicators pertain to space availability, housing cleanliness, animal behavior, and responses to stimuli (e.g., stocking density, human presence, and the introduction of new objects). Health indicators are broader and encompass metabolic disorders (e.g., ketosis, mastitis, fertility, and rumen fill), inflammation, injuries, and general pain. They also include consistent measurements (e.g., rectal temperature, heart rate, respiratory rate), database information (e.g., mortality rate, stillbirth rate, antibiotic usage), and findings at slaughter (e.g., carcass weight, bruising, etc.). Finally, although the term '*iceberg'* was included in the search string, only 3 research articles out of the 25 retrieved incorporated the iceberg indicator, with inconclusive conclusions.

Table 13: Animal health and welfare indicator common across livestock systems.

Item	Times repeated	System	Type	Classification
Lameness	13	Ruminants (dairy and beef cattle, sheep, goats), broiler chickens, and pigs	Animal based	qualitative
Body condition score	10		Animal based	qualitative
Soiling	9		Animal based	qualitative
Mortality	7		Resource based	quantitative
Skin lesions	7		Animal based	qualitative
Tail lesions	4		Animal based	qualitative
Behaviour	6	Ruminants (dairy and beef cattle, sheep), and broiler chickens	Animal based	qualitative
Respiration rate	5		Animal based	quantitative

Vocalization	4		Animal based	qualitative
Mastitis	5	Dairy cattle, goats, and sheep	Animal based	qualitative
Rectal Temperature	4		Animal based	quantitative
Water supply	5	Dairy cattle and broiler chickens	Resource based	quantitative

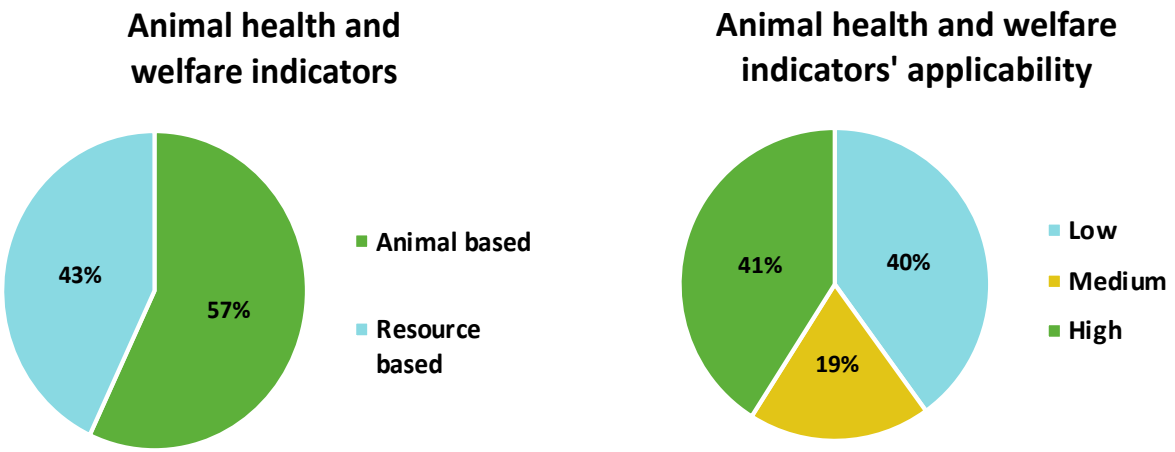


Figure 27 Animal health and welfare indicators characterization and applicability

In addition to the studies included in this search, it is important to note the extensive research and development work conducted by the AWIN (Animal Welfare Indicators) project. The AWIN project, funded by the EU, aimed to enhance the welfare of animals by developing scientifically validated indicators and protocols. These indicators helped assess various aspects of animal welfare, ensuring their physical and psychological well-being. More information on the AWIN indicators and protocols can be found here: https://animalwelfarehub.org/awin-protocols/. Likewise, the Welfare Quality network (https://www.welfarequalitynetwork.net/es-es/informes/assessment-protocols) developed extensive research and protocols for evaluating animal welfare across various Livestock production systems.

4.6. Soil Health

Figure 28 presents the timeline of publications under the MSS for soil health; 2015 (8), 2020 (9), and 2022 (8) derived the highest number of publications, with 18% of all publications coming from Spanish based research, jointly followed by the UK and Czech Republic (10%). In relation to species type, it can be seen from figure 30 that cattle dominate this research area within this MSS, representing within 77% of all studies, however, importantly, 65% of this work focused on the impact of cattle slurry/manure spread on different soil types and associated impact on chemical, biological, and physical indicators. Although, sheep (12%) and poultry (9%) were represented in a smaller number of studies, the significance of their inclusion was heavily based on respective slurry/manure applications. Overall, across all 78 studies, 472 indicators (figure 31) were used to measure the impact of ELPs on the chemical, biological, and physical quality, fertility, and overall health of European soils. From this, (1) carbon (including SOC, total carbon, microbial biomass carbon) was the most

frequently used indicator (n=49), followed by (2) nitrogen (including total N) (n=36), (3) phosphorous (n= 30), (4) pH (n=28), (5) K (n=23), (6) enzyme activity (n=6), and (7) earthworms (n=5) and bulk density (n=5). From this, the average number of indicators per study was 2, with 268, 159, and 45 indicators used to measure the chemical, biological, and physical impact respectively.

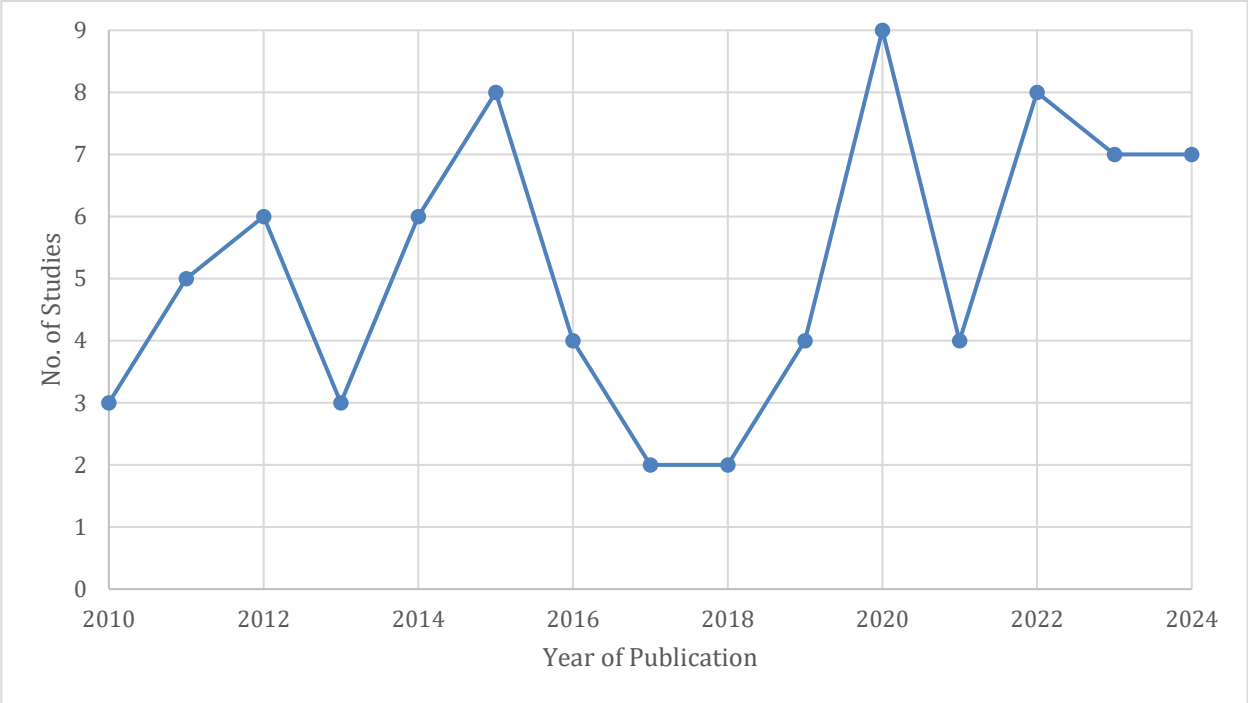


Figure 28: Year of publication for articles within Soil Health MSS.

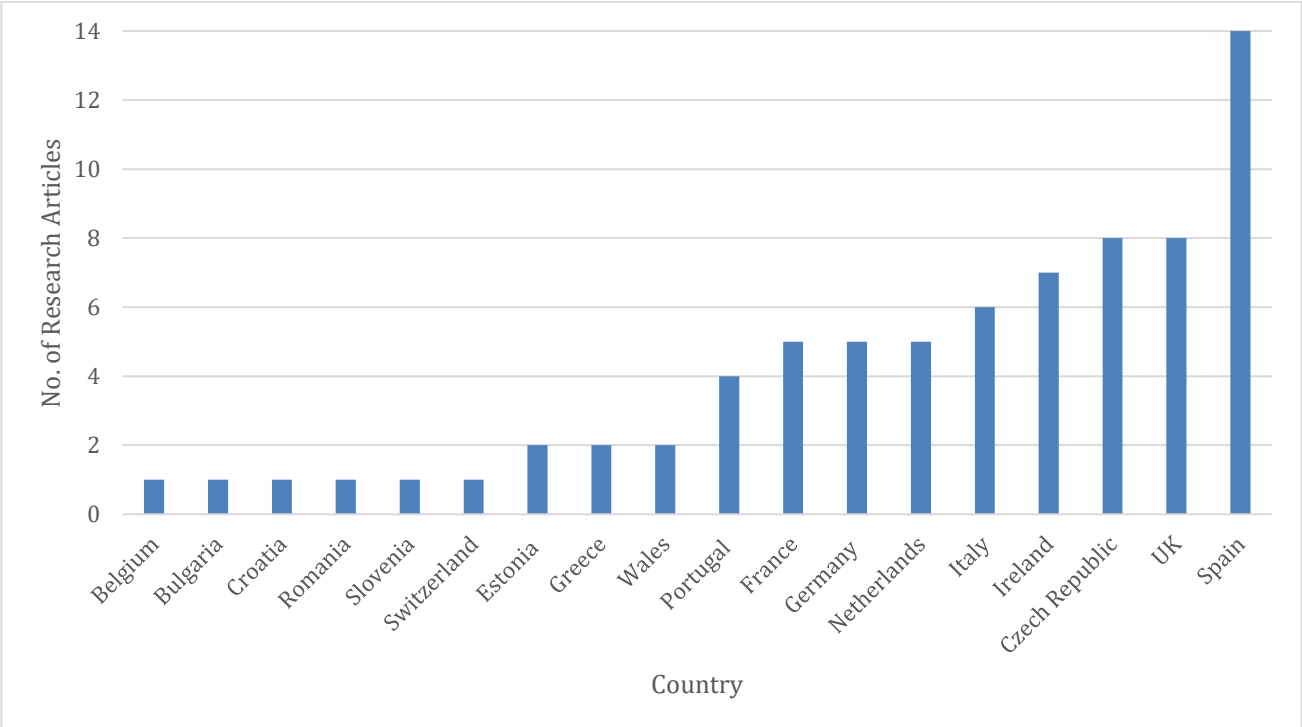


Figure 29: Geographical distribution of articles within Soil Health MSS.

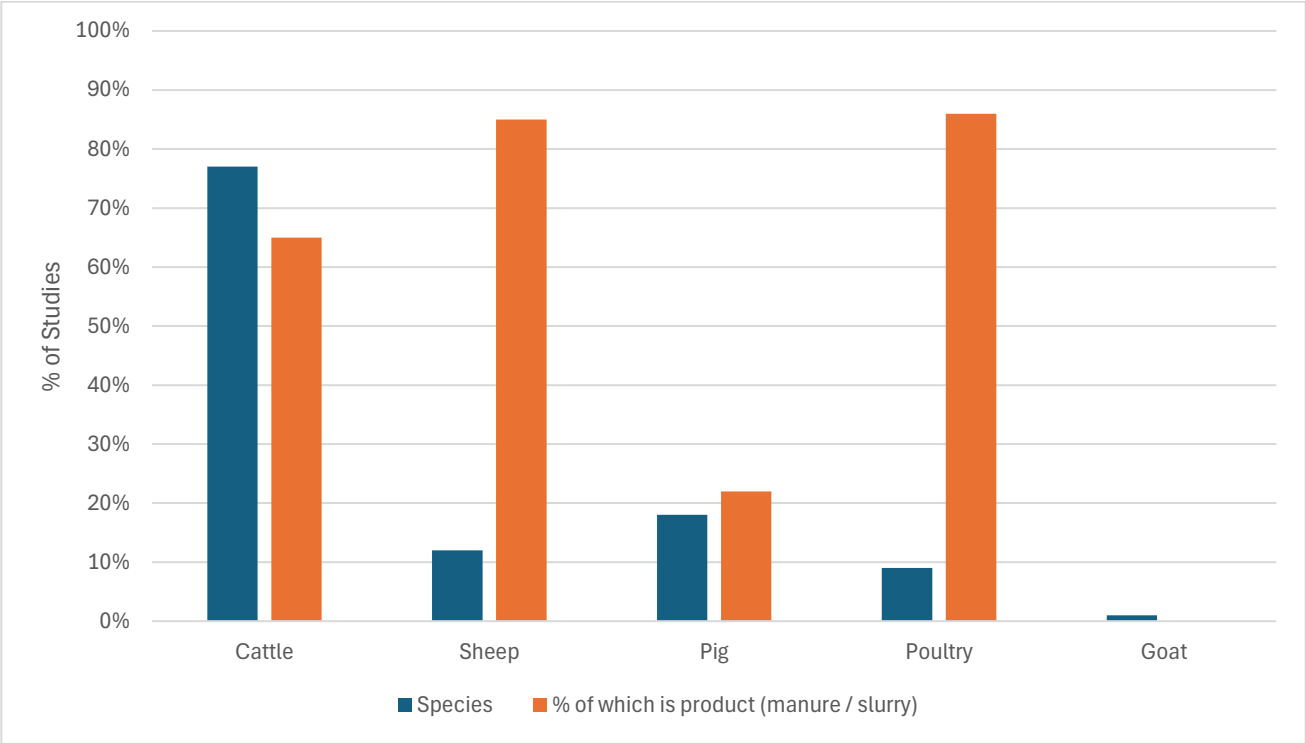


Figure 30: Breakdown of species type and product of articles within Soil Health MSS.

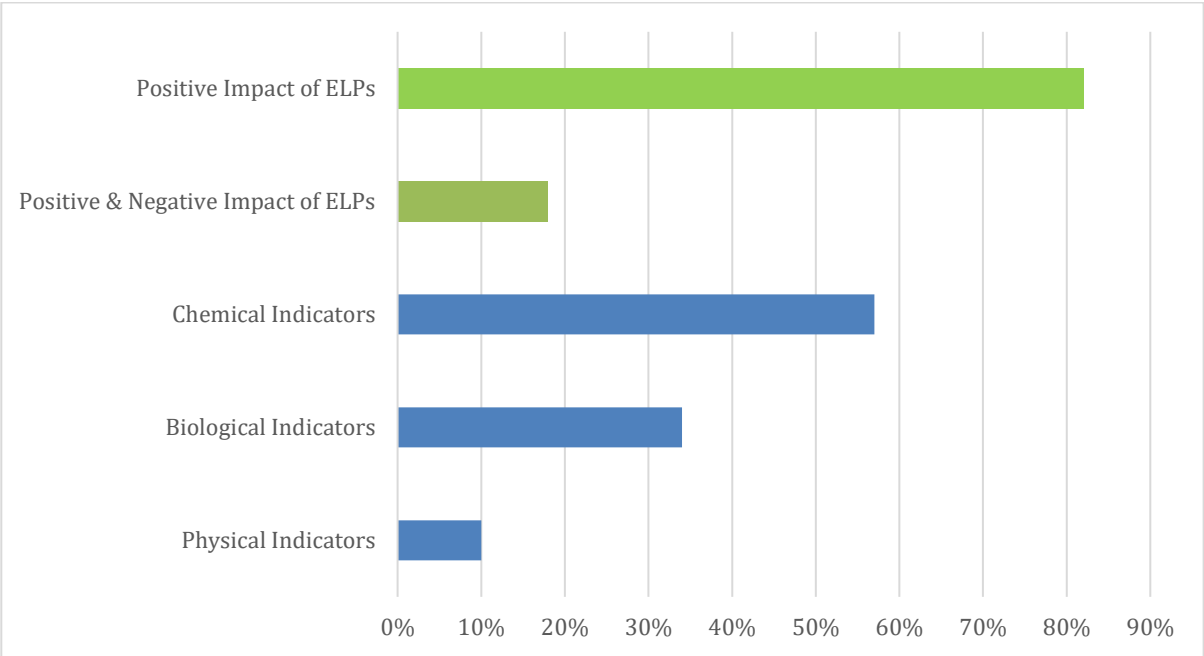


Figure 31: Reported impact of ELPs on Soil Health and number of chemical, biological, and physical indicators.

4.7. Biodiversity

Most studies focus on a single country (n = 90), while four include two or more countries. Two additional studies, both employing modelling approaches, are conducted at the EU level. In total, 26 countries are represented in the selected publications, with France, Spain, and Italy among the most frequent (figure 32). The studies are distributed across the ten-year period from 2015 to 2024, with nearly two-thirds (61 out of 96) published after 2020.

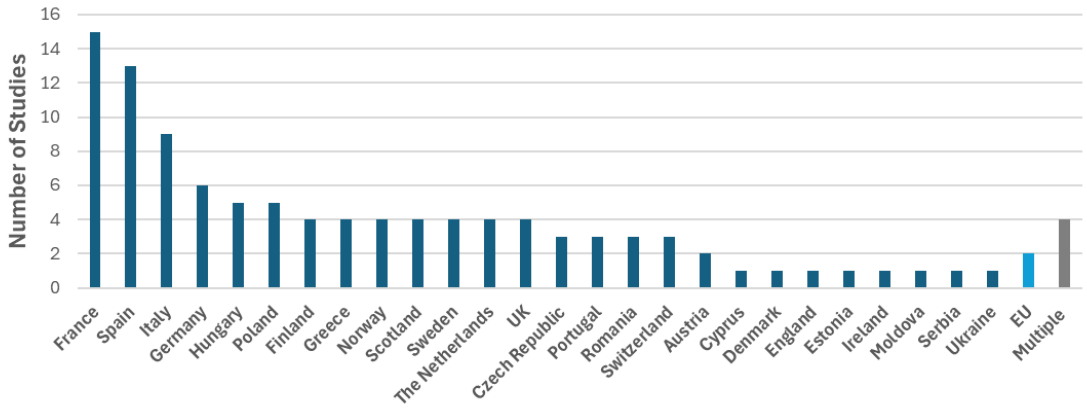


Figure 32: Geographical distribution of the studies in the review list.

Regarding livestock systems, 41 studies adopt a multi-species approach, from these, 20 studies assess two species, 10 three species, and 11 cover four or more species. Fifty studies focus on a single livestock species, with cattle being the most frequently represented (26 studies). Five studies do not specify the livestock species. Across all studies, cattle are the most frequently represented species (figure 33), appearing in 62 studies, followed by sheep (44 studies), and horses (20).

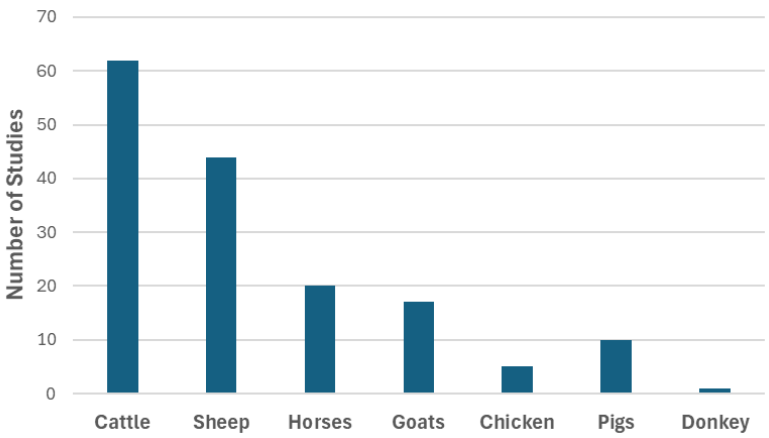


Figure 33: Number of studies including each livestock species. Counts include both single-species and multi-species studies (Biodiversity)

Most studies focus on extensive management systems (n = 36), followed by those comparing extensive and intensive systems (n = 18) (figure 34). Unassisted grazing (e.g., rewilding systems, producing environmental services) is examined in 9 studies, while intensive management alone is addressed in 4. Other management types not explicitly linked to intensity (e.g., specialized livestock farms vs. mixed farms) are considered in 15 studies, either individually or in combination with other approaches. In terms of comparison approaches (figure 35), most studies compare land uses with or without livestock grazing and differences in livestock intensity, followed by comparisons based on livestock type (includes species, breeds and production sectors (e.g., beef vs dairy cattle)), farming system, and timing of grazing. Three studies compare diets or livestock products.

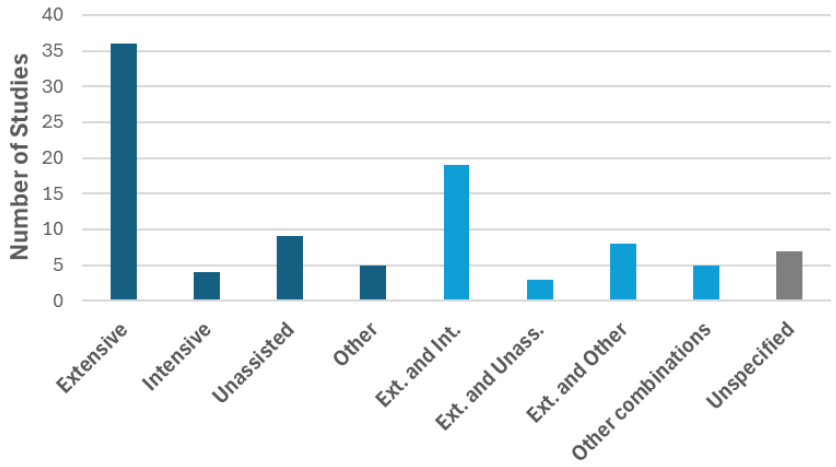


Figure 34: Number of biodiversity studies by livestock management type, including single (dark blue) and combined (light blue) approaches ("Other"-other types of management).

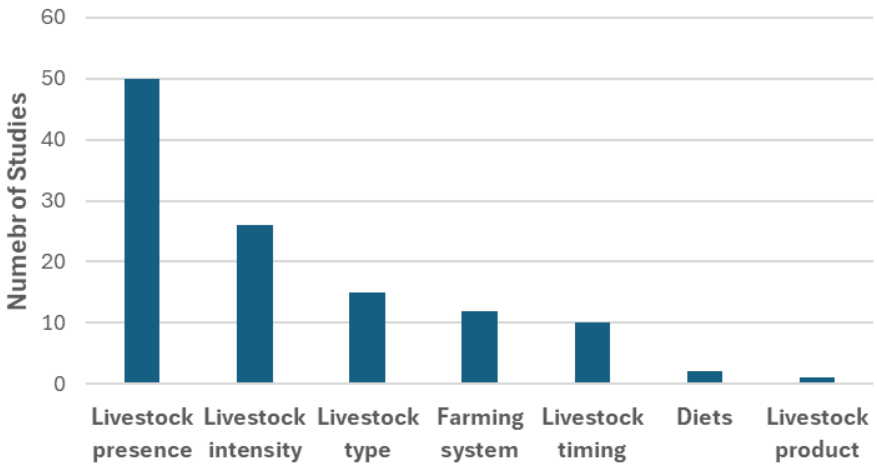


Figure 35: Number of studies including each approach used to assess livestock effects on biodiversity; studies may cover more than one approach.

For the biodiversity MSS, a total of 57 unique indicators were derived across all studies. It is important to note that these 57 identified indicators included removing non-relevant variables and merging similar ones into a 'harmonised set'. Thus, this is a conservative estimate, as it does not account for scale- or taxa-specific variants,

for example, species richness of birds, beetles, grasses; or alpha (local) vs. gamma (regional) richness; plant cover of grasses, shrubs, or orchids – including these variants would result in a much higher number.

The biodiversity indicators reported across the reviewed studies were highly diverse, reflecting the range of biodiversity concerns and the studies' focus. Indicators were grouped into six classes: five aligned with the Essential Biodiversity Variables (EBV) framework [Pereira et al. 2013], and one additional class for indicators not directly covered by the EBV categories. Each study could report multiple indicators within a given class, as well as indicators from multiple classes.

Most studies report community composition indicators (e.g., species richness, diversity, species composition), followed by indicators of ecosystem structure (e.g., vegetation structure, habitat richness, ecological infrastructure), and of species populations (mostly, the abundance of monitored species populations) (figure 36). Examples of biodiversity indicators not directly covered by EBVs ("Other") include scoring systems using proxy variables, and LUC-driven biodiversity loss. Whilst figures' 37 and 38 present the impact of livestock, including intensity (respectively), with respect to the biodiversity components targeted by the studies, 48 included variables related to plant communities or species, 17 focused on vertebrates (primarily birds (15 studies), followed by mammals (8) and herptiles (3)), 15 addressed invertebrate communities, and 25 examined overall ecosystem-level variables.

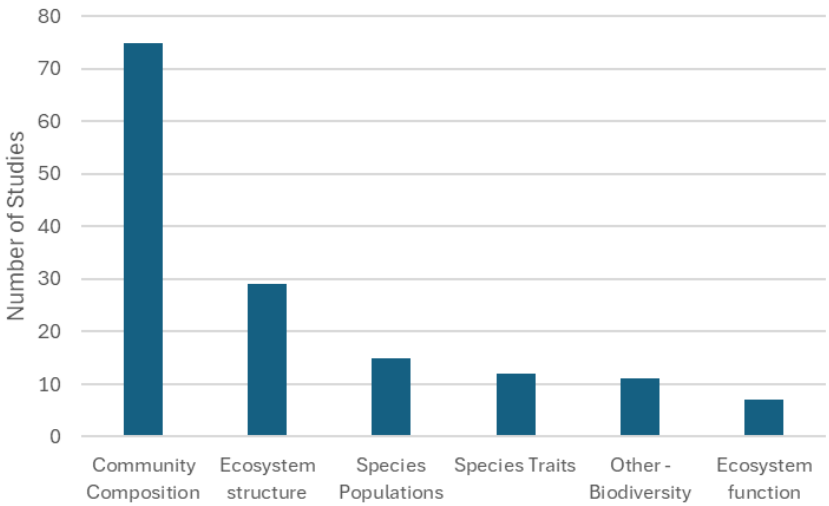


Figure 36: Number of studies reporting biodiversity indicators per Essential Biodiversity Variable (EBV) class. "Other-Biodiversity" includes indicators not directly linked to EBVs.

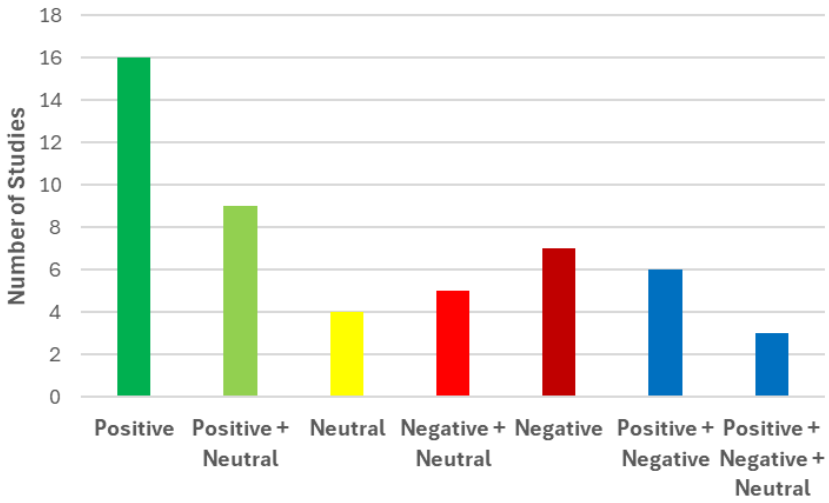


Figure 37: Number of studies that report positive, negative and neutral impacts on biodiversity, and combinations of these categories.

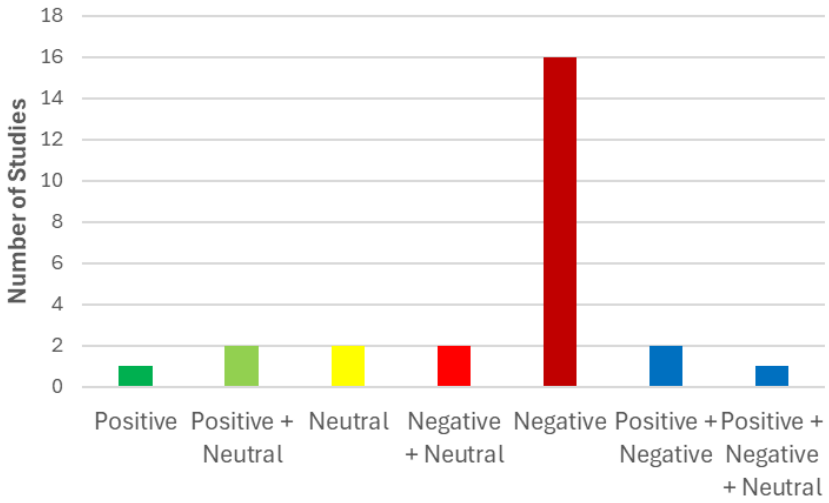


Figure 38: Impact of increasing livestock intensity. Number of studies that report positive, negative and neutral impacts on biodiversity, and combinations of these categories.

4.8. n-LCA

Fo n-LCA, data synthesis focused on three key outcomes of interest:

1. **Environmental Indicators**
2. **Nutritional Indicators**
3. **Combined Nutrition-Environmental[8] Indicator**

For this IC, most studies were published in 2023 (41%) and 2024 (22%), with fewer in earlier years; 2020 (15%), 2021, (15%), 2022 (12%), 2019 (10%), 2018 (2%). All eligible studies were from Europe, Spain being the most represented (20%). Other countries included Sweden, "Europe" and the UK (12%), the Netherlands and Germany (10%), France, Belgium, and Switzerland (7%), and Italy and Finland (5%). Ireland, Wales, and Denmark each contributed one study (2%). Regarding livestock types, dairy (73%), beef/red meat (66%), and poultry (63%) were the most studied, followed by pork (41%). Fewer studies focused on unspecified meat (17%) and lamb/mutton (17%) and one study each on goat, rabbit, venison, and offal (2%). The most common system boundary was "unspecified" (34%), followed by "cradle-to-gate" (17%). Other boundaries included but were not limited to "cradle-to-mouth/consumption" (10%), "cradle-to-grave" (7%), “cradle to plate” (5%), and “cradle to fork” (2%).

Environmental Indicators

The environmental indicator demographics of the 41 studies are summarised in table 14. Numerous environmental ICs were identified (n = 22). Land use (LU) (59%), GHGe/carbon footprint (54%), and water use (WU) (footprint/scarcity/consumption/resource depletion/ blue water use) (44%) were the three most frequently studied environmental ICs. These were consistently applied across a range of livestock types, including dairy, beef, poultry, pork, lamb, mutton, venison, and other categories. Eutrophication (34%), acidification (27%), and global warming potential (24%) formed a second tier of commonly studied ICs, primarily focused on dairy, beef, poultry, and other meat types. Fossil fuel depletion (15%), ozone depletion (12%), particulate matter (10%), biofortification (10%) and cumulated energy demand (7%) focused on dairy, beef, pork, and poultry whereas biodiversity loss (7%) also covered lamb and venison. Ionizing radiation (5%, dairy and pork), respiratory effects (5%, dairy and beef), phosphorus application (5%, pork, poultry, beef, dairy, meat) nitrogen application (2%, meat, dairy, poultry, pork), ecosystem effects (2%, pork only) and photooxidant formation (2%, pork, poultry, beef, dairy) were studied in the minority. Animal welfare-related indicators such as animal life years suffered (ALYS), loss of animal lives (AL), and loss of morally adjusted animal lives (MAL) were each studied once, specifically for meat and poultry.

[8] Here, the focus was placed on GHG emissions.

Table 14: Descriptive statistics of environmental indicators in n-LCA MSS; frequency of studies, livestock types, and contributing authors.

Environmental Indicator	*Frequency of Studies*	*Livestock Type*	*Author(s)*
Land use (LU)	24	Dairy, beef, poultry, lamb, mutton, pork, red meat, processed meat, goat, offal, venison	(Aidoo *et al.*, 2023), (Cardinaals *et al.*, 2024), (Colizzi *et al.*, 2023), (Cortesi, Bris and Pénicaud, 2024), (Detzel *et al.*, 2022), (Green, Nemecek and Mathys, 2023), (Green *et al.*, 2021), (Herrmann *et al.*, 2024), (Katz-Rosene *et al.*, 2023), (Kesse-Guyot *et al.*, 2024), (Kovanen *et al.*, 2024), (Lee *et al.*, 2021), (Mazac, Järviö and Tuomisto, 2023b), (McAuliffe *et al.*, 2023), (Meier *et al.*, 2024), (Mertens *et al.*, 2019), (Mogensen, Hermansen and Trolle, 2020), (Muñoz-Martínez *et al.*, 2023), (Paris *et al.*, 2022), (Röös *et al.*, 2020), (Saget *et al.*, 2021), (Strid *et al.*, 2021a), (van de Locht *et al.*, 2024), (Van Mierlo *et al.*, 2022)
Greenhouse gas emissions (GHGe) / Carbon footprint (CF)	22	Beef, dairy, poultry, pork, lamb, mutton, venison, meat, red meat, white meat	(Abejón *et al.*, 2020), (Colizzi *et al.*, 2023), (Cooreman-Algoed *et al.*, 2020), (Esteve-Llorens *et al.*, 2019), (Green *et al.*, 2020), (Green, Nemecek and Mathys, 2023), (Green *et al.*, 2021), (Hobbs *et al.*, 2020), (Lee *et al.*, 2021), (McNicol *et al.*, 2024), (Mertens *et al.*, 2019), (Mogensen, Hermansen and Trolle, 2020), (Muñoz-Martínez *et al.*, 2023), (Strid *et al.*, 2021a), (van de Locht *et al.*, 2024), (Zhang *et al.*, 2023), (Cambeses-Franco *et al.*, 2021),(Coluccia *et al.*, 2022), (Esteve-Llorens *et al.*, 2019), (Katz-Rosene *et al.*, 2023), (Simon, Copena and Pérez-Neira, 2023), (Singh-Povel *et al.*, 2022)
Water Use (WU)/ Water Footprint/ Water Resource Depletion/ Blue Water Use/ Scarcity-Weighted Water Use/ Water Consumption	18	Beef, pork, lamb, mutton, venison, meat, dairy, poultry, processed meat, red meat, white meat	(Cambeses-Franco *et al.*, 2021), (Cardinaals *et al.*, 2024), (Colizzi *et al.*, 2023), (Cortesi, Bris and Pénicaud, 2024), (Detzel *et al.*, 2022), (Green *et al.*, 2020), (Green, Nemecek and Mathys, 2023), (Green *et al.*, 2021), (Herrmann *et al.*, 2024), (Katz-Rosene *et al.*, 2023), (Kovanen *et al.*, 2024), (Mazac, Järviö and Tuomisto, 2023b), (Meier *et al.*, 2024), (Muñoz- Martínez *et al.*, 2023), (Paris *et al.*, 2022), (Strid *et al.*, 2021a; van de Locht *et al.*, 2024), (Van Mierlo *et al.*, 2022)
Eutrophication (freshwater/marine)	14	Dairy, beef, poultry, red meat, pork, lamb, mutton, offal	(Aidoo *et al.*, 2023), (Colizzi *et al.*, 2023), (Cortesi, Bris and Pénicaud, 2024), (Detzel *et al.*, 2022), (Green *et al.*, 2020), (Green, Nemecek and Mathys, 2023), (Hobbs *et al.*, 2020), (Katz-Rosene *et al.*, 2023), (Kovanen *et al.*, 2024), (Mazac, Järviö and Tuomisto, 2023b), (Paris *et al.*, 2022), (Röös *et al.*, 2020), (Saget *et al.*, 2021; Van Mierlo *et al.*, 2022)
Acidification	11	Dairy, beef, poultry, red meat, pork, lamb, mutton	(Aidoo *et al.*, 2023), (Colizzi *et al.*, 2023), (Cortesi, Bris and Pénicaud, 2024), (Detzel *et al.*, 2022), (Green *et al.*, 2020), (Green, Nemecek and Mathys, 2023), (Hobbs *et al.*, 2020), (Katz-Rosene *et al.*, 2023), (Mazac, Järviö and Tuomisto, 2023b), (Paris *et al.*, 2022), (Saget *et al.*, 2021)
Global Warming Potential (GWP)	10	Dairy, beef, red meat, processed meat, poultry, pork lamb	(Aidoo *et al.*, 2023), (Cardinaals *et al.*, 2024), (Kesse-Guyot *et al.*, 2024), (Mazac, Järviö and Tuomisto, 2023b), (McAuliffe *et al.*, 2023), (McAuliffe, Takahashi and Lee, 2018), (Meier *et al.*, 2024), (Saget *et al.*, 2021), (Simon, Copena and Pérez-Neira, 2023), (Sonesson *et al.*, 2019)

Nutritional indicators

The nutritional indicator demographics of the 41 studies, are summarized in Table 15. Many different nutritional indicators were identified throughout studies (n=56). The combined nutrition scores were of greatest significance; the Digestible Indispensable Amino Acids Score (DIAAS) was the most common indicator (20%) in studies from 2020-2024 across beef, dairy, poultry, and pork. Various Nutrient Rich Food/ Nutrient Rich Diet (NRF/NRD) indexes were used, including NRD 9.3 (10%, poultry, beef, lamb, pork, dairy, rabbit, meat, red meat, processed meat), NRF 9.3 (7%, poultry, red meat, dairy, and beef), and NRF 11.3 (5%, beef, pork, lamb, venison, dairy, and poultry). The LIM Index appeared in 7% of studies (2021-2024) focusing on beef, pork, poultry, and dairy. Unique indices like the HEalth Nutritional Index (HENI), weighted protein score (pro), and Alternative Healthy Eating Index (AHEI) also appeared in 2% of studies.

Individual Nutrients/Scores

Protein quantity was the most frequently assessed individual nutrient score (22%) across beef, dairy, poultry, pork, lamb, red meat, and offal. Calcium (Ca), riboflavin (B2), vitamin B12, selenium (Se), and zinc (Zn) were each assessed in 7-10% of studies all focusing on beef, lamb, poultry, pork, and dairy. Omega-3 fatty acids, monounsaturated fatty acids (MUFAS) and saturated fatty acids (SFA) were more frequently included (5%) in studies than Omega-6 fatty acids (2%), but all assessed beef, poultry, pork, and lamb. A variety of other nutrients were included in 2-5% of studies, primarily focussing on beef and dairy with some consideration for lamb, poultry, and pork.

Table 15: Descriptive statistics of nutritional indicators in n-LCA MSS; frequency of studies, livestock types, and contributing authors.

Nutritional Indicators	*Frequency of Studies*	*Livestock Type*	*Author(s)*
Combined nutrition score			
Digestible indispensable amino acids score (DIAAS)	8	Beef, dairy, poultry, pork	(Coluccia *et al.*, 2022), (Fernández-Ríos *et al.*, 2024), (Green *et al.*, 2020), (Herrmann *et al.*, 2024), (Mazac, Järviö and Tuomisto, 2023b), (McAuliffe *et al.*, 2023), (Singh-Povel *et al.*, 2022), (Van Mierlo *et al.*, 2022)
Nutrient rich diet (NRD 9.3)	4	Poultry, beef, lamb, pork, dairy, rabbit, meat, red meat, processed meat	(Abejón *et al.*, 2020), (Simon, Copena and Pérez-Neira, 2023), (Esteve-Llorens *et al.*, 2019), (Mertens *et al.*, 2019)
Nutrient-rich food index (NRF) 9.3	3	Poultry, red meat, dairy, beef	(Esteve-Llorens *et al.*, 2019), (Green *et al.*, 2020), (Strid *et al.*, 2021b)
LIM index	3	Beef, pork, poultry, dairy	(Green *et al.*, 2021), (Kyttä *et al.*, 2023), (Herrmann *et al.*, 2024)
Nutrient-rich food index (NRF) 11.3	2	Beef, pork, lamb, venison, red meat, dairy, poultry	(Strid *et al.*, 2021a), (Strid *et al.*, 2021b)
Individual nutrients considered			
Protein quantity	9	Beef, dairy, poultry, pork, lamb, red meat, offal	(Zhang *et al.*, 2023), (Van Mierlo *et al.*, 2022), (Singh-Povel *et al.*, 2022), (Simon, Copena and Pérez-Neira, 2023), (McAuliffe, Takahashi and Lee, 2018), (Kovanen *et al.*, 2024), (Detzel *et al.*, 2022), (Cortesi, Bris and Pénicaud, 2024), (Röös *et al.*, 2020)
Calcium	4	Beef, lamb, poultry, pork, dairy	(Cortesi, Bris and Pénicaud, 2024), (Kovanen *et al.*, 2024), (McAuliffe, Takahashi and Lee, 2018), (Mogensen, Hermansen and Trolle, 2020)
Riboflavin (vitamin B2)	3	Beef, lamb, poultry, pork, dairy	(Mogensen, Hermansen and Trolle, 2020), (McAuliffe, Takahashi and Lee, 2018), (Kovanen *et al.*, 2024)
Vitamin B12	3	Beef, lamb, poultry, pork, dairy	(Mogensen, Hermansen and Trolle, 2020), (McAuliffe, Takahashi and Lee, 2018), (Kovanen *et al.*, 2024)
Selenium (Se)	3	Beef, lamb, poultry, pork, dairy	(Mogensen, Hermansen and Trolle, 2020),(McAuliffe, Takahashi and Lee, 2018), (Kovanen *et al.*, 2024)
Zinc (Zn)	3	Beef, lamb, poultry, pork, dairy	(Mogensen, Hermansen and Trolle, 2020), (McAuliffe, Takahashi and Lee, 2018), (Kovanen *et al.*, 2024)

Combined Nutrition-Environmental Indicator Results

The results in table 16 illustrate the change in GHGe (% or $kgCO_2eq$) when a nutritional indicator was incorporated into environmental-LCA of ASF – the nutritional-environmental functional unit (NFU).

Significant changes occurred in GHGe across all categories. Beef showed the most substantial decrease in GHGe, ranging from 67% to 96% across studies, when nutrition was factored within LCA using multiple nutritional indicators including NRF24, HENI, priority micronutrient value (PMV), new food equivalent (FEC), and % reference daily intake (%RDI). Lamb exhibited a considerable decrease in GHGe (57-94%) when considering PMV, omega-3 content, and %RDI. Both pork and poultry showed more moderate decreases in GHGe (40-60% for pork, 40-50% for poultry) based on PMV, NRD9.3 and %RDI indicators. Eggs demonstrated an approximate 50% decrease in GHGe when considering PMV. Dairy (milk) showed varied results with a 25-50% decrease in GHGe (NRF24, PMV, NRD9.3). However, there was a 25% GHGe increase in dairy (milk) noted when factoring the environmental impact weighted daily value score (EIWDVS).

When considering $kgCO_2eq$ changes rather than % change, beef, dairy, and poultry each showed a 0.15 $kgCO_2eq$ decrease when incorporating the energy-adjusted healthy reference diet score (HRDea). Dairy (milk) demonstrated inconsistencies in changes, from 0.15 – 0.96 $kgCO_2eq$ decrease (HRDea, DIAAS) to a 24.3 $kgCO_2eq$ increase (AHEI).

Table 16: Descriptive statistics of the combined nutrition-environmental impact of ASF categories, specifically changes in GHGe when incorporating nutritional indicators.

Food Category	Nutritional Factor	Frequency of Studies	GHGe Change	Author(s)
			% Change	
Beef	NRF24, HENI, PMV, FEC, %RDI	9	67-96% decrease	(Cardinaals *et al.*, 2024; Katz-Rosene *et al.*, 2023; Zhang *et al.*, 2023; Lee *et al.*, 2021).
Dairy (Milk)	NRF24, PMV, NRD9.3 EIWDVS	9	25-50% decrease 25% increase	(Cardinaals *et al.*, 2024; Katz-Rosene *et al.*, 2023; Esteve-Llorens *et al.*, 2019) (Aidoo *et al.*, 2023)
Lamb	PMV, Omega-3 content, %RDI	4	57-94% decrease	(McNicol *et al.*, 2024; Katz-Rosene *et al.*, 2023; Lee *et al.*, 2021).
Pork	PMV, % RDI	4	40 - ~60% decrease	(Katz-Rosene *et al.*, 2023; Lee *et al.*, 2021)
Poultry	PMV, %RDI, NRD9.3	7	40 - ~50% decrease	(Katz-Rosene *et al.*, 2023; Lee *et al.*, 2021; Esteve-Llorens *et al.*, 2019)
Eggs	PMV	1	~50% decrease	(Katz-Rosene *et al.*, 2023)
			KgCO_2eq change	
Beef	HRDea	1	0.15 kgCO_2eq decrease	(Colizzi *et al.*, 2023)
Dairy (Milk)	HRDea, DIAAS AHEI	3	0.15 – 0.96 kgCO_2eq 2eq decrease 24 kgCO_2eq increase	(Colizzi *et al.*, 2023; Coluccia *et al.*, 2022; Hobbs *et al.*, 2020).
Poultry	HRDea	1	0.15 kgCO_2eq decrease	(Colizzi *et al.*, 2023)

5. Discussion

The following discussion(s) details the " narrative " of the results and the key messages coming from the datasets of the eight respective impact categories. Here, discussion focuses on what the key messages/findings were and what they mean for ELPs. This is done by focusing on three key outputs: (1) **indicator**, what are the 'variable(s) of interest', (2) **impact**, the social, economic, and/or environmental 'actor' that the indicator impacts, and (3) **data/co-efficient**(s), the statistical significance of the indicator.

5.1. Economic

'Cattle' received the most attention in the last ten years, followed by small ruminants and monogastrics. Interestingly, this distribution is not always related to the economic size of each sector. The comparison between frequency of reviewed articles and economic size of each sector in 2024 (European Commission, 2025) shows that, for cattle, the attention of the research has been consistent with the economic size of the sector, with 47% of the reviewed articles and 56% of the economic size. Nevertheless, for the highlighted period, small ruminant systems generated about 3% of the total economic output of the European livestock sector, while monogastric systems generated about 45% of the total economic output. These figures contrast sharply with the attention of the literature that has been placed comparatively more on small ruminants (29%) than monogastrics (24%).

There are different reasons that could explain this imbalance. Firstly, sheep and goats constitute an important source of income in disadvantaged areas and are a significant part of the European cultural heritage. Both factors, in a context of low profitability and insufficiency for supplying the domestic market, has made those systems a target for public support (European Parliament, 2008; Soriano et al., 2024). Secondly, small ruminant systems are frequently associated with pasture-based extensive systems. These systems provide positive externalities and public goods, which are often more complex to quantify and, therefore, attract interdisciplinary research (Ripoll-Bosch et al., 2013). Finally, as opposed to small ruminants, monogastric production is frequently characterized by concentrated sectors with a smaller number of highly intensive, vertically integrated large companies, with little or no public support (European Parliament, 2019, 2020). This lower level of support also reduces the reporting requirements, making less data publicly available (Sullivan et al., 2024).

Mapping of indicators

Most of the mapped indicators corresponded to profitability indicators. These findings coincide with previous literature (Díaz de Otálora et al., 2021; Latruffe et al., 2016; Lebacq et al., 2013; van der Linden et al., 2020). Additionally, durability, autonomy, and diversification received less attention. Particularly, diversification is the economic objective that received the least attention in the literature.

Different arguments can be discussed to explain this trend. Firstly, the traditional approach for analysing economic performance has been dominated by the analysis of productivity, income, costs, and overall profitability (Arvidsson Segerkvist et al., 2020; Gunnarsson et al., 2020; Lebacq et al., 2013). There has been a more recent shift in policy towards broader economic objectives such as fairness, resilience, and diversification. This is reflected in the Farm to Fork Strategy and objectives of the new Common Agricultural Policy (CAP) (European Comission, 2020, 2022). Nevertheless, as this is a recent change, it will take time to see reflected the results of research adapting to the current policy environment. In this sense, the transition from FADN to Farm Sustainability Data Network (FSDN), broadening the available data, will aid in this transition process.

Secondly, classifying the different indicators and objectives among a cause-effect chain may help to understand the distribution. Different authors (Bockstaller et al., 2015; Bockstaller et al., 2011; Lebacq et al., 2013) classify sustainability indicators in a continuum between causal or means-based indicators, based on a causal variable that will generate an impact; and measured effect indicators, which measure the actual impact or effect. Following this framework, profitability indicators tend to measure the actual effect and final objective of farming systems and economic activity, i.e., the result generated. Alternatively, durability, autonomy and diversification are more related to causal indicators, as they tend to measure variables that will impact economic performance.

Thirdly, data availability may influence the frequency of indicators. This is particularly true for some indicators that require sensitive data, such as solvency or debt management. Additionally, the existence of public databases, such as FADN, facilitates the use of secondary data for research purposes. On the contrary, for using indicators that are not based on this database, data collection may constitute a barrier. Finally, some of the indicators that appear less frequently are related to concepts that are still being discussed in the literature, and where the level of consensus is lower. This is the case, for example, of resilience or diversification, where definition, impact and ways of measurement might still not be completely clear (Paas et al., 2021; Wilczyński & Kołoszycz, 2021).

Relationship between livestock sector and economic objectives

The association test performed returned a statistically significant relationship between the livestock sector studied and the economic objective. Particularly, the dairy sector presented more profitability indicators and less durability indicators than expected. One explanation for this trend relies on the sector targeted by the different studies. On the one hand, half of the articles analysing durability indicators targeted more than one livestock system. On the other hand, just 30% of the articles analysing profitability indicators targeted more than one livestock system. Because of that, distribution of durability indicators tended to be more homogeneous among livestock systems. Oppositely, profitability indicators, that tended to be based

on just one livestock sector, concentrated more heavily on dairy farming. Nevertheless, the reasons of this trend are not completely clear. Further research is needed to better understand its causes.

Functional units

One of the finding of the review was the diversity of units used to express identified indicators. Units, generally a monetary value, were expressed in different currencies, including Euros, Sterling Pounds, United States Dollars, Romanian New Leu, Polish Zloty Equals, among others. This is not surprising as reviewed studies focused on different countries in the EU, EEA, and UK. Moreover, these values were expressed either as a total per farm, e.g., euro per farm per year, or as a function of other production factors, as shown in Figure 7. Similarly, to the use of different functional units in Life Cycle Assessments (LCA), indicator denominators varied depending on the purpose of the study (Kim et al., 2017). For example, values per land area were used to analyse land productivity or to compare farms of different scales. Values per labour unit were used to analyse labour productivity and compare with substitute activities, e.g., average income in other sectors. Unlike the use of indicators as total values, including a denominator can facilitate the comparison among farms and studies if formulas and models used to generate the indicators remain the same and raw data is collected in similar ways.

The findings of the economic SLR emphasised the diversity of methodologies used for calculating the economic indicators. Particularly, many different names were used to refer to a single concept. This diversity was mostly found in the income subtheme. For instance, more than 25 different names were used to refer to “gross farm income”, as defined in the FADN methodology (European Commission, 2020). Among others, these names included terms such as contribution margin, EBITDA (Earnings Before Interests, Taxes, Depreciation and Amortization), gross profit margin, profit before subsidies, and profit after subsidies. Conversely, at times, the same name represented frequently different concepts. This was notably the case of “gross farm income”, which intermittently included overhead costs, labour costs, or subsidies in its calculation. Moreover, many articles included economic indicators but did not explicitly describe what methodology followed for obtaining them, jeopardizing the transparency of the process. Overall, the amplitude of used units, the variability of research time and location, and the frequent use of total values, make it hard to compare different articles by the results they obtained.

The Farm Accountancy Data Network (FADN) establishes the methodological standard for calculating different economic indicators (European Commission, 2020). This methodology determines clearly different income indicators, and how each of them should be calculated. This method is aligned with international good practices related to bookkeeping and financial analysis (Argilés & and Slof, 2001). Although an important proportion of the literature follows this approach, there are many studies that choose to follow an alternative methodology. Because the same terminology is sometimes used to call different indicators, it

is difficult to compare study outcomes and draw a clear and quantified picture of the economic impact of ELP systems.

Overall, the SLR findings highlight the need to unify the terminology surrounding economic indicators to improve replicability, comparability, and transparency in livestock research. As the FADN methodology is already established and commonly used across Europe, it is an obvious choice to guide this process. The transition to FSDN also provides an opportunity to expand indicators of economic objectives that are not yet commonly assessed in the literature (e.g., fairness, resilience, diversification) and become a reference in these areas.

5.2. TCA

Methods applied:

Abatement cost curve versus monetisation factor

In the 50 identified TCA studies there are two major types of methods that have been applied for the estimation and calculation of the monetary value of the externalities:

1. studies that estimate an "own" abatement cost curve, based on the data that had been gathered in the particular study and
2. studies that use available monetisation factors for the calculating the monetary value of the externality.

In our 50 TCA studies, 28 studies estimate an "own" abatement cost curve and 22 studies use an available monetisation factor.

Abatement costs versus damage costs

Furthermore, the studies can be differentiated according to the valuation method. In our 50 TCA studies, three general valuation methods can be found: 1) the externality is monetized according to the abatement costs needed to reduce or cease the negative externality, 2) the externality is monetized according to the damage costs that arise due to the presence of the externality, and 3) the externality is monetized according to an available market price or other type of benefit. In our 50 TCA studies, 36 studies use abatement costs as valuation method. These are all studies that calculate their own abatement cost curve (28) plus an number of studies (8) that use a monetisation factor based on abatement costs. 18 studies use the damage cost approach for the monetisation of the externality, all studies make use of available monetisation factors. 8 studies make use of other valuation methods, such as using the market price as monetisation factor (e.g. the market price for CO_2-rights in the ETS). In some cases a combination of valuation methods is used in one study e.g. the monetisation of climate change can be based on abatement costs while the externality eutrophication is based on damage costs.

Monetisation factor

The monetisation factor that is applied in the study depends on the externality addressed and the indicator used to measure the externality. For instance, the externality global warming has one dominant indicator and that is CO_2-equivalent. On the other hand, externalities such as eutrophication can be described by several different indicators, such as kg P, kg PO_4, kg NO_x emission to air, kg NH_3 to air, kg NO_3 to surface water, kg N surplus on farm level, % P-reduction, kg NH_3 abated. The variation of monetisation factors is huge. This does not only count for externalities that can be described by different indicators, but also for externalities with one dominant indicator, such as global warning. Even is the case of CO_2-equivalent the variation in monetisation factor is very large, ranging from 45 to 195 euro per ton of CO_2-equivalent.

Sources of monetisation factors

In the 22 studies that apply an available monetisation factor, three sources turn out to be the major suppliers of monetisation factors: German Federal Environment Agency (2007), Environmental Prices Handbook (Bruyn et al. 2018 and 2023) and Ecocost (2023).

Uncertainty and difficulties

In 25 out of 50 articles uncertainty is not dealt with. 16 articles include a kind of sensitivity analysis on characterisation factors (8), monetisation factors (5) or input-output prices (3). In 4 articles simulation was used to deal with uncertainty. The main difficulties mentioned are related to data availability (10), data quality (3) and availability of methodology (5). In 10 articles no difficulties were mentioned.

In the TCA studies a wide range of indicators are used, depending on the externality(ies) addressed in the study. Most of the reviews TCA studies mention environmental issues, where climate change, acidification and eutrophication are most frequently addressed. Social impacts are rarely taken info account. Biodiversity is regarded as important, but is still scarcely addressed in the reviews of TCA studies. The reason for this may be the lack of data and knowledge with respect to the dose-response relationship in ecosystems and its effect on biodiversity. For instance, the effect of externalities of livestock systems on biodiversity may be positive or negative, depending on the livestock system and ecosystem that is taken into account.

In the reviews of TCA studies we find marginal abatement costs and marginal damage costs, either based on “own” data and based on calculation with an available monetisation factor. Sometimes, market prices are used as a monetisation factor. Marginal abatement costs and marginal damage costs vary widely, depending on the section of the marginal cost/damage curve and other circumstances the study is placed in. The use of marginal abatement costs or marginal damage costs should be preferred, since market prices rarely reflect the marginal cost of an externality.

Issues considering data quality and the use of models increases the necessity to implement sensitivity analyses in order to interpret and discus the impact of data quality and models on the final results.

5.3. Social

The literature review reveals significant gaps in the assessment of the social impact of ELP. We found only twelve studies that were published in the last 15 years, most of which focus on isolated case studies. The studies use different impact assessment approaches, weighting methods, impact subcategories, indicators, and inventory indicators. They also had different geographical and sectoral coverage, resulting in a fragmented understanding of social impact across countries, animal types, and production systems in Europe. This hinders the development of a comprehensive and comparative social impact evidence base for policy and practice.

From all the various social subcategories assessed in the studies, local employment, fair salary, and occupational health and safety were assessed most. Workers emerged as the most consistently evaluated stakeholder group. This could suggest a shared recognition of these as central in social impact assessments in ELP or could reflect that for these impact subcategories and for this stakeholder category data was the most easily available. Efforts are required to assess other impact subcategories and stakeholder categories.

Our review demonstrated a substantial variation in the impact subcategories, indicators, and inventory indicators used to assess social impacts. Furthermore, the number of impact subcategories, indicators, and inventory indicators also varied widely between the studies. For example, the number of indicators per impact subcategory ranged from one to thirty. This highlights a reliance on data availability rather than on standardized methodological guidance. This also makes that results of studies difficult to compare which complicates building an overarching picture of the social impact of ELP. Efforts are required to standardize impact sub-categories, indicators, and inventory indicators to be used in social impact assessment of ELP.

Only two studies reported quality of and uncertainty in input data, despite the potential influence on results and their interpretation. This emphasizes the need for greater use and transparent reporting of data quality and sensitivity analyses, which are essential to understanding how data limitations affect the findings.

In summary, the limited number of studies, their fragmented scope, inconsistent methodologies, and poor data transparency, are a major barrier for a coherent and reliable picture of social sustainability impact of ELP systems. Developing a standardized set of impact subcategories, indicators, and inventory indicators, methodological standardisation regarding weighting, and improved data quality reporting will be crucial for advancing social impact assessment of ELP systems and making it fit for responsible decision-making.

5.4. Greenhouse Gases

Enteric CH4:

The key studies selected for this review have been published as a result of large international collaborations that could have access to large databases with individual animal records within a range of regions, dietary regimes and production systems. Others developed national-specific models (i.e. Netherlands and France following a Tier 3 approach and Norway an advanced Tier 2, both for dairy cattle). The following conclusions can be drawn for each animal category.

Dairy cattle:

Within model categories, an intercontinental model with the most available independent variables performed best with root mean square prediction error (RMSPE) as a percentage of mean observed value of 16.6%, 14.7%, and 19.8% for intercontinental, EU, and United States regions, respectively. Less complex models requiring only DMI had predictive ability comparable to complex models. indicated that the ability to predict enteric CH4 production increases with increasing model complexity. As observed previously, DMI is the key factor for enteric CH4 production prediction. Although complex models that use DMI, NDF, EE, MF, and BW had the best performance for predicting CH4 production, models requiring only DMI or DMI + NDF had the second best predictive ability and offer an alternative to complex models. Milk production and composition variables are key factors to predict CH4 yield, whereas milk composition and animal variables are key factors to predict CH4 intensity. Model evaluation specific to individual regions compared with that of intercontinental based models suggests that enteric CH4 production, yield, and intensity can be accurately predicted from both intercontinental models and regional-specific models with similar performance. Although prediction performance was similar, intercepts and slopes of variables in optimal prediction equations developed on intercontinental basis differed from those developed on regional basis. Therefore, revised CH4 emission conversion factors for specific regions are preferred to improve CH4 production estimates in national inventories. The models developed have already been included in the IPCC 2019 update for emissions factors.

Beef cattle:

The datasets used in this review comprise data from several regions and a wide variety of forage contents. As observed previously, DMI is the key factor for predicting beef cattle enteric CH4 production. Non-linear models with DMI as the only independent variable did not outperform their counterpart linear models. However, linear models depending on DMI and dietary forage content or these two covariates plus BW commonly had an improved predictive ability. Separate equations for lower-forage (≤18%) and higher-forage (≥25%) data also improved predictive ability. Model evaluation specific to European higher-forage, North American higher orage and Brazilian higher-forage diets compared with that of intercontinental

higher-forage diet models suggests that overall enteric CH4 production is more accurately predicted by region-specific models, although in many cases the best intercontinental and region-specific models may perform similarly. The equations developed in the studies considered commonly had higher precision and less prediction error with similar accuracy compared to the extant equations that were evaluated previously (i.e. IPCC 2006). Evaluation of CH4 emission conversion factors indicated that region-specific and in particular dietary forage content-based Ym values are required for adequately predicting beef cattle CH4 production in national or global inventories. Use of equations specific to dietary forage proportion reduced the uncertainty of estimating beef cattle eCH4 emission compared with the IPCC Tier 2 methodology.

Sheep:

Dry matter intake is the key variable for predicting enteric CH4 production in sheep. However, increasing the model complexity by including body weight (BW), and organic matter digestibility (OMD) improved prediction performances for the universal equations, whereas diet composition had a minor impact. Prediction performance was increased through developing age-specific models to accommodate the physiological and dietary differences. For adult sheep (>1-year-old), models should include DMI alone. On the contrary, for young sheep (<1- year-old), the universal models can be applied if DMI and BW are included as key variables. The main findings indicate that appropriate universal equations accurately predict CH4 production across different diets and climatic conditions without compromising prediction performance. The equations developed in the present study commonly had lower prediction errors than the extant IPCC 2019 equations. Equations for CH4 yield led to low prediction performances, with DMI being negatively and BW and OMD positively correlated with CH4 yield. These findings suggest that the proposed universal equations, in combination with the age-specific equations represent an opportunity to improve ovine CH4 production.

Manure management:

During the analysis of the database templates, many variables were identified for storage and for housing. Some of them are necessary for the characterization of the livestock systems, others for the conversion of the results into reference units such as kg CH4 kg−1 VS stored or % of N excreted, and the majority for the interpretation of EFs. There were no studies that included all variables listed in the database; this is not surprising given that each study had different objectives and therefore had different data requirements. However, to ensure that published gaseous emission measurements can be readily converted to EFs, we encourage researchers to include the reporting of crucial manure and animal variables, as listed by Webb et al. (2020). Some variables, such as N and VS excreted, are also very rarely reported because their determination is often not considered for experiments that focus on emissions from housing-based manure systems. These variables require the implementation of specific protocols that are more likely to be included in experiments dealing with animal nutrition. Concerning CH4 EFs for housing, most of the collated

studies reported CH4 concentrations within the housing and therefore may have included enteric CH4 from ruminant livestock (and potentially pigs). Because it was not possible to distinguish the source of the CH4 in these studies, we recommend caution in the application of these data as manure EFs.

5.5. Animal Health and Welfare

The literature review on AHW indicators revealed a greater concentration of research articles within the past five years (2019–2024), indicating a known but still-growing academic and practical interest in the field. Although the literature search primarily focused on European livestock systems, including studies from other countries, it highlighted the need for continued development in this field while demonstrating that certain AHW indicators have broad applicability and the potential to be effectively implemented across diverse global production systems. Identifying 100 animal health and welfare indicators emphasized the diversity and complexity of evaluating welfare across ELPs. The greater prevalence of animal-based indicators (57%) compared to resource-based ones (43%) may reflect not only a growing preference for direct animal observations, often seen as more accurate or practical to implement, but also underlying limitations in data management, availability, and infrastructural capacity within production systems. This highlights the need to strengthen resource-based data collection and monitoring systems to enable a more comprehensive and balanced approach to animal welfare assessment. They are categorised as animal-based and non-animal-based (e.g., resource-based or management-based) indicators.

Animal-based indicators, or outcome measures, show directly how the animal experiences the way it is kept and managed, and cover all indicators that are measured directly on animals, such as changes in behaviour, appearance, health, and physiology. Non-animal-based indicators, or input measures, are variables that are not measured on the animals but in their environment, and demonstrate what the animals are provided with to ensure good welfare and protection. Input measures are relatively easy to measure and provide information on housing systems and management (e.g., space availability, floor type, feeding space, weaning age, or the use of legally permitted mutilations such as castration or tail docking). However, whereas input measures are directly linked to the production system the animals are housed in, output measures (e.g., animal-based measures) are less dependent on the production system and therefore are more easily applied across countries and across production systems. Resource-based indicators are predominantly reported in their raw measurement units (e.g., kg, L, %, minutes, respiration rate per minute), which introduce variability that hampers direct comparisons across different livestock systems and contexts.

Establishing a standardized scoring framework for these indicators is therefore essential. It would help to translate heterogeneous measurements into normalized scores, enabling and facilitating clearer cross-system comparisons. Harmonizing these scoring metrics would not only improve insights into resource allocation and management practices but also support the development of robust, integrated assessment

models for animal welfare. Building upon this idea, further research could explore consensus-driven methodologies involving experts from diverse sectors, ensuring that the standardized metrics capture both the nuances of resource availability and the practical realities of different livestock environments. This collaborative approach would likely yield scoring systems that are not only scientifically sound but also adaptable to the varying scales and contexts of ELPs.

Notably, indicators such as lameness and body condition score (BCS) appeared consistently across species and production systems, reinforcing their value as widely applicable welfare metrics. However, both assessments involve a degree of subjectivity and require observer training, and their ease of implementation can vary across species. Additionally, inconsistencies in scoring systems present challenges for standardization and interpretation. For instance, in this review, BCS was simplified by classifying animals as either thin (score = 0) or fat (score = 5). Yet, scoring systems differ between species. Beef cattle are commonly assessed on a 0 to 10 scale, while dairy cattle are typically assessed on a 1 to 5 scale. Under such simplifications, a one-point change in BCS could have a more significant implication for animal health in dairy cattle than beef cattle, raising concerns about comparability and the potential loss of nuance in cross-species assessments. Moreover, the feasibility of conducting BCS evaluations can vary even within ruminant systems; for instance, it is generally more straightforward to assess BCS in dairy cattle than in dairy goats, due to anatomical and handling differences. A similar issue arises with lameness scoring, which can be more challenging in certain species or environments. These limitations highlight the need for context-specific calibration, standardized protocols, and adequate training to ensure reliable and meaningful application of these indicators across different livestock systems.

Furthermore, the predominance of qualitative over quantitative indicators (73% vs. 27%) presents strengths and limitations. Qualitative assessments often capture nuanced animal behaviors and conditions, but also introduce observer bias and subjectivity. In contrast, though less common, quantitative indicators provide standardized and reproducible measures, facilitating benchmarking and longitudinal monitoring. A key insight emerging from this review is the variability in the applicability of indicators, categorized as low, medium, or high. This variation is particularly important when considering the translation of welfare assessment frameworks across production systems with differing infrastructures, species-specific needs, and resource availabilities. For instance, certain indicators like behavioral responses or respiration rates may be more practical in intensive systems where close monitoring is feasible. In contrast, others, like soiling or water availability, might be prioritized in extensive or pasture-based settings.

Further categorization into health and comfort domains could underscore the multifaceted nature of animal welfare assessment. Comfort-related indicators such as stocking density, housing cleanliness, and behavioral responses may capture the animal's immediate physical and behavioral environment. In contrast, health indicators such as mastitis, rectal temperature, and mortality rates may tend to reflect longer-term physiological conditions and underlying systemic issues. Notably, while mortality was

consistently included as a key resource-based welfare indicator across species, only one study identified it as an iceberg indicator, despite its potential to signal broader welfare problems. This classification approach promotes a more holistic understanding of animal welfare; however, it also highlights the importance of selecting context-appropriate and species-specific indicators to ensure meaningful and accurate assessments.

In the last years more works have focused on 'iceberg indicators', which can reflect, capture, or summarize several welfare consequences/issues. Therefore, the time required for assessment is reduced accordingly. Despite the classic protocols are still very time consuming, they have produced a large set of data, which can be used to derive more simple assessment suing representative 'iceberg indicators, e.g., indicators that are easy and quick to implement for both scientists and stakeholders (e.g., farmers, veterinarians, farm advisors, official or private inspectors, NGO s, slaughterhouses), and that can be used irrespective of the type of production system (e.g., intensive, extensive, organic).

This review highlighted the importance of a balanced, adaptable, and context-sensitive approach to welfare assessment. Future research should aim to validate these indicators across more diverse systems and geographic regions, emphasizing the use of standardized, quantitative tools that maintain sensitivity to animal well-being.

5.6. Soil Health

For the purposes of this discussion, only statistically significant indicators and respective co-efficient(s) reflecting the (1) chemical, (2) biological, and/or (3) physical, and/or chemical impact of ELP on the health, fertility and quality of European soils will be reported.

Chemical indicators:

Chemical indicators are the most frequently chosen indicators to measure the impact of ELPs on soil fertility, quality, and overall health (n=117). In terms of significance, focus was placed on the effect of livestock slurries/manures on the chemical health and composition of various soils and associated yield, production, and productivity. Addressing the significant issue of water quality from nutrient run-off risk from livestock production, Over an 18-year period, McCarthy et al., (2024) quantified K balance of an Irish grassland-based (clay loam podzolics) dairy farm including K lost to water, to relate the balance between K entering and existing the farm to soil K fertility status. K leaching from the farm was 59 ± 7.4 during 2022/23 (mean ± SE kg ha−1). Overall, average farm K balance was 41 ± 12kgha−1 and ranged between −36 and 136kgha−1, with leaching to groundwater representing the majority (55%) of K exiting the farm. Despite this significance, results on the impact of ELPs on the chemical health of soils was overwhelmingly positive. For example, In the Netherlands, Deru et al., (2018) reported marginal improvements in soil indicators for dairy (140 kgN ha−1 as inorganic fertilizer and 216 kg N-total ha−1 as cattle manure) over

semi-natural (sheep/cattle grazed 43 kg N-total ha−1 yr−1 cattle manure) production. For example, an increase of: 0.4 pH; total C 1.5 g 100 g soil−1; TN 0.4 g 100 g soil−1; SOM 3.5 g 100 g soil−1; total P 0.2 g 100 g soil−1), but semi-grasslands had higher bulk density ~0.55 g cm−3. Previously, With yield doubling after 4 years, K increasing by 254 mgkg−1, magnesium by 245 mgkg−1; P by 44-54 mgkg−1, and N increasing by 50% in Cambic hyperskeletic leptosols in the Czech Republic, Duffková et al., (2015) concluded that a (cattle) slurry application at an annual rate up to 120 kg N ha−1 seems to be an acceptable compromise high soil fertility, adequate herbage production, environmental protection, and nature conservation for species-rich grasslands.

Looking at both chemical and biological indicators, in Italy, a long term (50+ year) study by Giacometti et al., (2013) examined the interrelationships between chemical and microbiological quality indicators of soil (ustochrepts) and their ability to differentiate plots under contrasting fertilization regimes. The soil was cropped with maize (Zea mays L.) and winter wheat (Triticum aestivum L.) and received (1) no organic fertilization (control), (2) wheat straw and maize stalk (crop residue) or (3) cattle manure in combination with increasing levels of mineral N (N0 and N200). When comparing manure applications to control: total organic carbon TOC increased by 2g kg−1 soil); total nitrogen increased 0.2g kg−1 soil); pH increased by 0.3; microbial biomass carbon by 20 mg kg−1 soil) by 20. Further, there were significant increases in all enzyme activities (Arginine Dehydrogenase β-glucosidase Protease Urease) by almost 100% compared to control and 50% to crop residue. Soil amendment with cattle manure built up soil organic carbon (+13%), increased nutrient content (+31% of extractable C and +19% of extractable N), including that of available P (+47%), and stimulated microbial growth (+34%) and activity (+8%).

Whilst Baizán et al., (2021) measured an increase of 40% in P uptake for maize on spanish sandy soils when dairy slurry was applied (compared to the control without P supply), Shakoor et al., (2022) found pig slurry to be significant when applied (146, 281, 534 kg N ha−1) at sowing of a barley crop on Spanish silty loam soils – with OC increasing by 20% and TN by 33% (highest slurry), Olsen P increased by 3.1 mgP|kg −1 soil for every 100 kg P ha−1, 110% increase in K. Nonetheless, the research concluded that the lowest slurry rate was able to maintain the highest grain yields while improving fertility. More recent work by Matsi et al., (2025) measured the effect of cattle manure (40 Mg ha−1 yr−1 and 80 Mg ha−1 yr−1) on corn yield on Greek calcareous loam soils (11-year study), results indicated that dry aboveground biomass yield was 10 Mgha higher to control (unfertilized) and 1-2.5 Mgha higher compared to inorganic fertiliser. Further, there was a 120% increase in P (18.5 mg|kg) compared to inorganic fertiliser and 30% increase in K, yet there were no changes in soil pH but TOC increased by ~40%.

Physical and Biological indicators:

In relation to physical and biological indicators (n=65), the effect ELP, including grazing and application of slurry and manures, on the Enzymatic activity and earthworm populations of different soil types dominated

the research focus. For example, investigating the influence of three different French land use systems (continuous maize, pasture/maize rotation, permanent cattle grazed pasture) on the relationships between earthworm populations and the number of earthworm burrows in a (sandy loam cambisol) soil profile, Pérès et al., (2010) found that permanent pasture presented significant higher earthworm abundance (153.3 individuals m−2) than rotation pasture (24.6 individuals m−2) (84%) – burrow numbers were also 31% higher under pasture than maize. Looking at the effect of pig slurry, in a Spanish (10 year) study by Biau et al., (2012) on a petrocalcic calcixerept soil type, pig slurry was applied (45 m3 ha-1, equivalent to 315 kg nitrogen (N) ha-1 year−1) (PS45) to maize and chemical fertilizer (300 kg N ha-1) (N300) along with a N-free control (N0). Results found a 100% increase in earthworm count when pig slurry is applied compared to chemical N, and a 21% increase in microbial biomass carbon (mg C/kg soil) – but it did not increase crop yield or OM compared to mineral. In a larger scale, eight fertilization strategies were compared in a field trial on Alfisol in Belgium (humid temperate climate) including cattle slurry (CSL at 77.38 mgha) and farmyard manure (FYM at 64.33 mgha). Significant results showed a positive impact of FYM on enzyme activities, in particular β-glucosidase and β-glucosaminidase activity (10%-60% increase compared to other fertilisers) Moeskops et al., (2012).

Looking at the impact of livestock slurry on the biota of French meadow (rotational with crop) soils, Ponge et al., (2013) found that cattle and pig slurries caused a 40% increase in Anecic earthworms, 46% for Endogeic earthworms and a 41% increase in macroacroarthropods and mollusks – but there were small reductions in Epigeic springtails. As a result, the authors recommended to consider only biota, 'and preferably a limited array of easily identifiable organisms or bulk biological variables such as microbial biomass', in a composite indicator of soil health. More recently, in Slovenia, Chatzistathis et al., (2020) measured the impact of chicken manure (CM) on nematode biodiversity in wheat and rapeseed production, results indicated that genus biodiversity was significantly higher in treatments with CM (18% in wheat, 28% in rapeseed), whilst OM increased by 60%. Similarly, Sandor et al., (2022) investigated earthworm-enchytraeid-interactions during decomposition of two organic sources (barley straw and cattle manure) on German silty loam soils, finding a 110% increase in Enchytraeid populations under manure treatment, whilst, in Bulgaria (chernozem soils), a field trial by Vasileva et al., (2015) measured the dry mass yield of alfalfa forage to be 15.9% higher with manure compared to mineral fertilizer, there was also 614-1371 kg/ha additional root mass – with humus content 10.9 to 41.9% higher under manure treatment compared to mineral.

Coupled with the impact of ELP on various soil biota, there was significant research investigating the impact of livestock slurries/manures on levels of organic matter (SOM) and organic carbon (SOC) (including microbial carbon and biomass). Earlier work by Yagüe et al., (2012), found that pig slurry, applied at 10 t ha−1, whilst delivering nutrient benefits, also increased SOM (34%) and soil microbial biomass (53%) in Spanish silty loam soils. More recent work by Anderson et al., (2016) in German stagnic luvisols revealed

that, dairy production with legume in crop rotation (including manure applications), increased soil biomass carbon (Cmic) up to 87% and the Cmic-to-Corg (soil organic carbon) ratio of up to 60%. This was followed up by (Abdalla et al., 2022) who established a 45% and 65% in SOC on German stagnic luvisols when applied with cattle manure (20 tonnes ha−1 year−1) and cattle manure with synthetic fertiliser respectively – similar results were found by Bosch-Serra et al., (2020) on soil microbial biomass, which increased by 40% under dairy cattle slurry treatments in an 8-year Spanish study.

Although, Mayerová et al., (2023) found that soil aggregate stability increased under cattle manure treatments by 24.8% and 11% in the last two years of a four-year trial, more holistic work in the Netherlands by Deru et al., (2023) looked at the effect of organic/inorganic fertilizers on biotic/abiotic indicators of peat grasslands (terric histosoils). Results indicated that solid fraction manure increased earthworms (+35%) compared to the control (unfertilized), SOM increased significantly under cattle manure (~1g/100g), more than compost or slurry, whilst grass dry matter yield was similarly increased by all fertilizers (+7-11%).

General management of ELPs:

Aside from indicators measuring the impact of ELP on the chemical, biological, and physical health of soils, several studies investigated the impact of livestock grazing, particularly stocking rate and density. Results are mixed in terms of positive/negative impact. Notable research by McCarthy et al., (2016) evaluated the cumulative effects of alternative integrated (cattle) grazing strategies, stocking rate (SR) and grazing severities, on perennial ryegrass productivity on Irish clay loam soils. Three whole-farm SR treatments were compared over 4 complete grazing seasons: low (2.51 cows/ha; LSR), medium (2.92 cows/ha; MSR), and high (3.28 cows/ha; HSR). Results revealed total annual net pasture accumulation was greatest in HSR [15,410 kg of dry matter (DM)/ha], intermediate for MSR (14,992 kg of DM/ha), and least for LSR (14,479 kg of DM/ha). Thus, there was an increase in net pasture accumulation of 1,164.4 (SE = 432.7) kg of DM/ha for each 1 cow/ha increase in SR.

Conversely, two years previously, using the Visual Evaluation of Soil Structure (VESS), Askari et al., (2014) determined appropriate indicators (n=21) for a soil quality index (most responsive to management change) on twenty Irish grassland sites classified by three levels of management intensity (low, medium, high). Whilst initial results indicated that 45% of sites had good soil structural quality, 45% fair and 10% poor soil structural quality, the research found that increasing stocking rate was reported as a major factor in the reduction of soil productivity, whilst intensification can improve soil fertility in the short term due to fertilization, it increased soil compaction, erosion and degradation of physical attributes as well as SOC loss and reduction in nutrient availability, which resulted in poorer soil quality and reduced of soil productivity. Similarly, using the VESS method, Cui et al., (2014) measured the soil structural quality (Sq) of Irish grass-based beef and dairy production (management intensity). Whilst, the average Sq (1 = good 5 = poor) score

of all 20 grassland soils was 2.24, the research concluded that reduced soil quality (e.g. moderate soil compaction; reduced porosity) under high management intensity indicated that soil degradation might be a future threat to sustainable grassland productivity within high input/output systems.

Earlier work In Czech Republican cambisols by Elhottová et al., (2012) investigated the (10 year) impact of "cattle outdoor over-wintering practice". Upland pastures were compared under three different levels of cattle impact (SI – severe, MI – moderate, NI – no impact). Notably, pH was 3.1 higher under severe cattle impact compared to no impact; total N was 1.2 [g 100 g−1] higher; organic carbon 3.5 [g 100 g−1] and a 300% increase soil total biomass – with all measures of soil microbial activity increasing. Similar to McCarthy et al., (2016), looking at different grassland management of Croatian cattle production on luvisols, including no grazing, moderate grazing and heavy grazing (1.26 LU ha−1), Bogunovic et al., (2022) found significant differences in pH: no grazing (4.78) < moderate grazing (5.23) < heavy grazing (6.51). Additionally, SOM and TN were significantly different: heavy grazing (4.83% SOM; 0.25% TN) ≥ moderate grazing (3.35% SOM; 0.18% TN) ≥ no grazing (2.38% SOM; 0.13% TN). Soil P ranged from 9.6 at no grazing to 55.0 mg kg−1 in the heavy-grazing treatment. Importantly, similar to conclusions by Askari et al., (2014), carbon, N and P loss were significantly higher in heavily grazed plots than in moderately and ungrazed plots.

The significance of these findings emphasize the importance of grazing management regimes, and questions the role of livestock, particularly grazing intensities and stocking rates, on the short and long-term health of agricultural soils. On wet acidic soils in the UK, Kajzrová et al., (2022) found evidence of improved soil bulk density under mixed sheep and cattle grazing compared to cattle-only grazing over a 3-month summer grazing season, but, there was no evidence of significant improvements in soil bulk density after three months of grazing exclusion. This evidence suggests that livestock exclusion for a summer grazing season (e.g. by rotating fields for silage or hay across the farm) may not be an adequate strategy to alleviate soil compaction.

Looking more specifically at grassland management as opposed to grazing intensity, on Dutch marine clay soils, Lepema et al., (2020) measured grass productivity and soil chemical parameters of 'young' (5–15 years since last grassland renewal) and 'old' (>20 years since last grassland renewal) permanent grasslands, located as pairs at 10 different dairy farms. The research revealed that grassland N yield (without N fertilization) was significantly higher for old grassland compared to young grassland, due to higher soil organic matter, C-total and N-total contents. In summary, there was a 2.6% increase in SOM in old grass; total C 15.8 (g C. kg dry soil−1) higher in old grass; Ca, P and mineralizable N (57 mg N. kg dry soil−1) all higher in old grass, but K was lower and pH 0.1 higher in old grass. Thus, when the botanical composition of grasslands is high (>70% of desirable grasses), the presumed yield benefit of grassland renewal is offset by a loss of soil quality (SOM and N-total).

Lepema et al., (2020) concluded that, ‘accordingly, the current practice of grassland renewal within a relatively short time-span (every ten years) without considering the botanical composition, is counter-productive and not sustainable.’ From this, they also proclaimed that farm management should focus on minimizing the need for renewal by good grassland management, e.g., maintaining desirable grasses by grazing, ample fertilization, irrigation and preventing and ameliorating soil compaction. Building upon this, looking at the economics of grassland renewals/changes, a Welsh sheep trial by Cooledge et al., (2024) investigated sward type on soil quality (sandy clay loam) indicators, revealing that the additional costs to farmers utilising commercial herbal leys (with a typical seed cost of ca. £200–250 ha−1) compared to grass-clover leys (ca. £150 ha−1) is not currently rewarded through the delivery of greater below-ground ecosystem services.

5.7. Biodiversity

Regarding the impacts on biodiversity, studies comparing livestock presence and grazing intensity are particularly suitable for synthesis, as they represent the most common comparison types and allow for assessment along clear quantitative gradients (e.g., presence vs. absence, or lower vs. higher intensity). The analysis of these studies reveals two main patterns. First, livestock presence is frequently associated with positive impacts on biodiversity—or conversely, the absence of grazing with negative effects. Among the 50 studies addressing livestock presence, 34 report positive impacts, 21 report negative impacts, and 21 report neutral effects. Second, increased grazing intensity is predominantly linked to negative outcomes, with 21 out of 26 studies reporting negative impacts, 6 reporting positive impacts, and 7 reporting neutral effects.

Positive impacts of livestock presence are reported across a wide range of biodiversity components, including the richness and diversity of plant, invertebrate, and vertebrate communities, ecological infrastructure, and the maintenance of habitat quality for fauna. Conversely, negative impacts are also observed for the same components, particularly regarding plant community composition and diversity, habitat quality for target species, and in association with overgrazing. Additionally, nine studies report both positive and negative impacts, highlighting the need to account for trade-offs when assessing biodiversity outcomes. These include, for example, contrasting responses among taxonomic or functional groups with differing habitat requirements (i.e., ecological winners and losers).

In the case of increased livestock grazing intensity, negative impacts are mostly observed at high grazing levels, affecting multiple dimensions of biodiversity—from reductions in plant and invertebrate diversity to declines in mammal and bird presence and habitat availability, as well as overall biotic community simplification. In contrast, positive impacts are reported when very low-intensity regimes are compared with moderate grazing levels, including benefits such as increased plant community diversity and evenness, or improved habitat conditions for open-land bird species.

5.8. n-LCA (QUB)

The evidence from the n-LCA MSS reveals that incorporating nutrition into LCAs significantly alters the perceived environmental impact of ASFs, often presenting them more favourably. Moreover, ASFs' exclusion from the diet may increase health deficiencies, while yielding only incremental environmental benefits. Here, commonly used nutritional indicators include protein quality (e.g., DIAAS), nutrient density (e.g., NRF index), and environmental ICs such as LU and GHGe, though variability across studies was evident. Notably, 64% of studies reported reductions in GHGe, with decreases of up to 97% for beef and 94% for lamb when nutrition was considered alongside environmental indicators. These significant results underscore the importance of integrating nutrition into LCA for a more holistic sustainability assessment of ASFs, while emphasising the need for careful selection of functional units in ASF analysis.

Environmental indicators:

Numerous environmental indicators are included within this systematic review, with primary focus on LU, GHGe and WU. Recent studies (e.g., Aidoo et al., 2023; Cardinaals et al., 2024) increasingly assess multiple environmental indicators, reflecting a shift towards more comprehensive evaluations. LU was widely studied (59%) covering diverse livestock types including goat, offal, and venison. GHGe indicator prevalence throughout studies (54%) reflects the ongoing global efforts to reduce emission, highlighting both progress and persistent challenges (United Nations, 2021). WU, discussed in 44% of studies across livestock types, is key when comparing sustainability of animal and plant foods. Despite common beliefs, plant-based foods often have a larger blue water footprint than ASF, while ASF contribute more to green and total water footprints (Harris et al., 2020). Although these indicators are widespread across studies, other key indicators like eutrophication, acidification, fossil fuel depletion, and biodiversity loss need further study to guide policy and consumer choices.

Nutritional indicators:

The diversity of indicators used across studies highlights lack of standardisation in ASF nutrition-environmental assessments. This resulted in methodological variations that complicated cross- study comparisons. Nevertheless, preference for combined nutrition scores over individual nutrient assessments suggests a shift toward holistic evaluation methods.

Protein measures, particularly DIAAS and protein quantity, dominate ASF nutrition-environmental assessments. This systematic review found that DIAAS was the most frequently used combined indicator (20%), reflecting its merit in evaluating protein quality and digestibility. Given the low DIAAS scores of plant-based alternatives, DIAAS remains the most accurate indicator for assessing single-source protein quality (Moughan and Lim, 2024). NRF indexes were widely used across livestock categories with many variations, indicating a trend towards comprehensive nutrient profiling and evolving methodologies. The

ability to apply NRF to individual foods, meals, and diets enhances its versatility (Drewnowski, 2010). Standardising nutrient inclusion is essential for NRF index use in nLCA and cross-study comparisons, yet it remains one of the most comprehensive methodologies available.

Calcium, riboflavin (B2), vitamin B12, selenium, and zinc were the most common individual nutrients among studies. Calcium is essential for bone health, abundant in dairy products, while B2 deficiencies are prevalent among children in regions with low milk and meat intake. Vitamin B12, exclusive to animal products, such as meat, dairy and eggs, necessitates supplementation for those omitting ASFs. Selenium levels vary by soil concentration, with beef, pork, chicken, and eggs serving as primary Western dietary sources (Espinosa-Salas and Gonzalez-Arias, 2023). Zinc is most bioavailable in ASFs such as organ and ruminant meats (Beal et al., 2023). Recognising these nutrients' roles in public health and their presence in AFSs could shift the narrative on ASF sustainability and guide nutrient-based functional units to address population deficiencies (Cortesi, Yannou-Le Bris and Pénicaud, 2024).

Nutritional-environmental indicators:

Typical approaches to LCA demonstrate that plant-based proteins generally have a lower environmental impact than ASFs (Detzel, 2022). Conversely, the results of this MSS evidences that when nutritional indicators, such as protein quality, bioavailability, and essential amino acid are incorporated within LCA, results differ, in some cases significantly – creating a more balanced view between livestock production, public health, and the environment.

Beef demonstrated the most pronounced benefits with a 67–96% GHGe reduction across studies and a decrease of 0.15 kgCO_2eq per unit. Similarly, lamb showed an 87–94% reduction in GHGe, particularly in upland/lowland systems. One study found that adjusting for DIAAS reduced beef's kgCO2eq/100g protein by 30% (McAuliffe, Takahashi and Lee, 2018), likely due to beefs high IAA content (Hodgkinson et al., 2018), notable as IAAs cannot be synthesised by the body (Elmadfa and Meyer, 2017). These results are significant considering the preconception that ruminant meats, particularly beef and lamb have the largest GHGe impact among food sources (Downs et al., 2024). The data reveals that ruminant meat can support dietary adequacy and planetary health, while beef's emissions can be mitigated to aid CO2 reductions (Mehmood et al., 2023). Given SDG 13 focus on taking urgent action to combat climate change through reducing CO_2 emissions by 45% by 2030 (United Nations, 2021) and SDG 3 focus on ensuring good health for all (United Nations, 2025), these results suggest that dietary recommendations should consider not only the environmental impact of ruminant meat but also its protein bioavailability.

Contrasting to ruminant meat, dairy (milk) results presented inconsistencies. GHGe reductions ranged from 25–50%, with CO_2eq emissions decreasing by up to 0.96 kg per unit. However, using EIWDVS, GHGe increased by 25%, and kgCO_2eq increased by 24.3kg under AHEI, showing the context-dependent nature of nutritional indicators and importance in the nutrients they encompass.

The comparison of dairy with plant-based milk alternatives (PBMAs) further complicates sustainability claims. A LCA considering protein quantity, quality, amino acids, and micronutrients (B2, B12, Ca) showed that to meet 24% of World Health Organisation essential amino acid requirements, soy drink required 253.3 gCO_2e, only 18% lower than semi-skimmed milk (GHGe=312gCO2e). Meanwhile, rice drink, despite its lower GHGe per unit, required excessive consumption (up to 246 glasses = GHGe=36,797gCO2e) to match the same nutritional value as dairy milk, making it a substantially less sustainable alternative (Singh-Povel et al., 2022). These findings show that PBMAs do not consistently outperform ASF in sustainability assessments, warranting a need to revisit dietary guidelines, such as the EAT-Lancet planetary health diet (EAT, 2019).

6. Conclusion

ELP plays a vital role within the European multifunctional, social–ecological system, delivering not only marketable goods but also a wide range of public goods. Despite this, due to an array of challenges, including environmental and policy shifts, there are significant pressures on ELP. Moreover, many of the positive impact of ELP are not measured, thus, there is a need to develop methods which measure the different contributions of ELP and their interrelationships. Indicator-based research methods are often used for this purpose. This research systematically identified, mapped, and collated indicators from the scientific literature representative of eight different impact categories. The principle aim was to establish the positive and/or negative social, economic, and environmental impact(s), including externalities, of ELP, supported with quantitative and/or qualitative value (data) of each indicator/eternality for each respective IC.

Overall, coupled with 16 externalities, this research has mapped 1,517 indicators from several scientific literature databases, which measure the positive/negative social, economic, and environmental impact of ELP.

Firstly, 518 indicators were derived from the economic MSS. Whilst the data from indicators developed a positive narrative of the economic impact of ELP, results were hugely reliant on ‘profitability’ as a measure/indicator, particularly for dairy production. Moreover, 35 indicators were identified for TCA, similar to economics, dairy production dominated the research focus. In total, 16 externalities were derived, but almost all of them focused on environmental impact – especially climate change. Despite a total of 96 indicators resulting from the social MSS, the most significant finding was how under-researched this strand of sustainability for ELP remains. Thus, a relatively negative narrative was derived from indicator values, but the limited number of studies, their fragmented scope, inconsistent methodologies, and poor data transparency, emphasizes caution when interpreting their results.

In relation to GHG, 183 prediction equations were established, with DMI and production variables (milk yield etc.) maintaining significance, but the choice of the FU became most critical, whilst regional-specific EF(s)

became an important recommendation – as noted by IPCC. The significance of the FU is clearer within the results of the (environmental) n-LCA MSS, wherein, despite a wide-range of nutritional indicators (n=56), three were of high significance within (carbon) n-LCA models: DIAAS, NRF, and NRD. Here findings reveal substantial reductions in the climatic impact of ELP – from a nutritional (consumption) level. The results of the AHW MSS were similar to the social MSS regarding the number of identified indicators (n=100) and the limitations of the research area. Here, a major drawback is the inadequate standardizations of indicator values, thus, it is essential to normalize indices for AHW indicators, enabling the integration of models. More detailed outputs were found within the soil health MSS, wherein a total of 472 indicators were established, resulting in a significantly positive narrative on the impact of ELP for this IC (especially the impact of livestock slurries/manures), similarly, values/data of the 57 indicators for biodiversity developed a positive narrative – but, importantly, 'over grazing' was highlighted as a critical 'threshold' for this positive impact for both ICs.

Although this research has mapped a large number of indicators to address the principle research aim, it is clear that there are significant research gaps and limitations measuring the social, economic, and environmental impact of ELP. Irrespectively, results measuring the impact of ELP should be considered with caution, as several trade-off exist, coupled with data and modelling limitations, and the significance of experimental approaches. Notwithstanding this, despite the results of the social and AHW MSS, albeit substantially limited, this results from this research have developed a significantly positive narrative of the impact of ELP. The findings from this research reinforce that policy-making must maintain and support the important role that ELP plays within a productive and environmentally sustainable multifunctional European landscape.

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