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Review: The challenge to integrate animal welfare indicators into the Life Cycle Assessment

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ABSTRACT

The transition to a more sustainable livestock sector represents one of the major challenges of our time. Life Cycle Assessment (**LCA**) is recognised as the gold standard methodology for assessing the environmental impact of farming systems. Simultaneously, animal welfare is a key component of livestock production and is intrinsically related to human and environmental well-being. To perform an overall on-farm sustainability assessment, it would be desirable to consider both the environmental impact and the welfare of the animals. The present work aimed to summarise and describe the methodologies adopted in peer-reviewed papers published to date, that combine animal welfare evaluation with LCA. Citations, retrieved from four bibliographical databases, were systematically evaluated in a multi-stage approach following the JBI and PRISMA scoping review guidelines. The searches identified 1 460 studies, of which only 24 were compliant with the inclusion criteria. The results highlighted how the environmental LCA was undertaken with a much more homogenous and standardised method than animal welfare assessment. When studies were grouped based on the type of animal welfare assessment performed: 16.7% used single welfare indicators, 45.8% multiple indicators, 8.3% applied existing validated protocols (i.e., TGI-200 and TGI-35L), 16.7% used non-validated protocols and 12.5% employed other methods. The papers were further classified with respect to the "5 Animal Welfare Domains Model": the most assessed domain was "environment" (90.5% of the papers%), followed by "health" (52.4%), "nutrition" (33.3%), "behavioural interactions" (28.6%) and "mental state" (9.5%). None of the studies assessed all the domains simultaneously. In addition, 66.7% of papers (n = 16) aggregated the animal welfare indicators into a final score. Within these, only four papers proposed to associate the animal welfare scores with the LCA functional unit. An overall sustainability score, calculated with several different approaches to summarise the information, was provided by 46% of the papers. In summary, despite the topic's relevance, to date, there is neither a consensus on the animal welfare assessment approach to be carried out (indicators selection and their aggregation) nor on the standardisation of an integrated animal welfare-LCA evaluation. The present review provides a basis for the development of common future guidelines to carry out a comprehensive, true-to-life and robust farm sustainability assessment.

Implications

An overall on-farm sustainability assessment that includes both the environmental impact (with Life Cycle Assessment) and the welfare of the animals is needed to help with the sustainability and resilience of the animal-sourced food farming systems globally. This review provides (1) an overview of the papers that used such a combined approach and (2) highlights how environmental impact assessment is undertaken with a much more homogenous and standardised method than animal welfare assessment. Expert collaboration, transparency and harmonisation of methods are necessary to enable a comprehensive sustainability assessment of farms, which also considers animal welfare.

Introduction

Within increasing pressures from such aspects as climate change and rising populations, our need to increase the sustainability and resilience in our farming systems is at an all-time high.

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In particular, animal welfare and environmental sustainability are considered priority issues by several organisations (European Commission, 2020; FAO-OIE-WHO, 2022; Keeling et al., 2019). In fact, it is undeniable how the livestock sector, in conjunction with other human activities, is the source of a wide range of negative environmental impacts, affecting the water, air and soil quality, biodiversity and the global climate (Leip et al., 2015). In fact, Gerber et al. (2013) reported that the livestock sector alone is responsible for 14.5% of anthropogenic greenhouse gas emissions.

Life Cycle Assessment (**LCA**) is an internationally standardised methodology (ISO, 2006a and 2006b) used to quantify the potential environmental impacts of a product from its origin until its final disposal. It has been identified as the best tool to assess potential environmental impacts (Commission of the European Communities, 2003) and it is currently used to calculate the environmental footprints of products (European Commission, 2021). Despite its wide use, it is a methodology that needs implementation, especially when applied to agricultural systems. In fact, environmental LCA has been criticised for being a product-based approach which fails to capture the full multifunctionality and complexity of farming systems (Van der Werf et al., 2020). Therefore, LCA tends to reward situations of greater intensification, without adequately taking into account other aspects that could instead be decisive for the long-term sustainability of production systems (e.g., reduction in soil quality and fertility, increase in soil erosion, impact on biodiversity and ecosystems, and animal welfare). This also explains why less intensive and organic livestock farming can often be penalised in terms of impacts per functional unit (Notarnicola et al., 2017). However, this lack of comprehensiveness should be seen as an opportunity to strengthen LCA, making it more suitable for agricultural systems.

Animal welfare is a key component of sustainable livestock production (Buller et al., 2018; Keeling et al., 2019; Broom, 2021) and the recommendation of the UN Committee on World Food Security, consider it as one of the key strategies to face the current challenges (High Level Panel of Experts on Food Security and Nutrition, 2016; Cox and Bridgers, 2019). This vision is emphasised by the "One Welfare" approach, which recognises the interconnections between animal welfare, human well-being and the environment (Pinillos et al., 2016),

When considering animal welfare, it is crucial to define it, as many definitions have been coined over the years. Even today, a universal definition for animal welfare is missing (Keeling et al., 2011), one of the most widely accepted is..." 'the physical and mental state of an animal in relation to the conditions in which it lives and dies" (World Organisation for Animal Health, 2022).

Many indicators have been developed to assess animal welfare. Generally, those can be divided into animal- (e.g., behavioural, physiological, pathological and productive indicators), resources- (e.g., housing, bedding, ventilation), and management-based (e.g., feeding, milking and the evaluation of human-animal interactions) indicators (EFSA Panel on Animal Health and Welfare, 2012). It is important to underline that the assessment of animal welfare requires a multidimensional approach (Mason and Mendl, 1993) through the combination of all of these indicators (EFSA Panel on Animal Health and Welfare, 2012). Several protocols were developed which promised to provide a valid, reliable and feasible animal welfare assessment such as the Welfare Quality® (2009) (Botreau et al., 2009) and the Animal Welfare Indicators (AWIN) projects (European Commission, 2022a). However, each protocol relies on specific choices and assumptions that could be influenced by biases of the working groups, especially when the indicators are also aggregated to obtain a final score. The aggregation of indicators is a critical phase and must be done transparently and with caution, as the output might have important repercussions for policy and decision-making of the stakeholders (Spoolder et al., 2003; Sandøe et al., 2019). Beyond the choice of the indicators, it is worth recalling that almost all the animal welfare protocols developed to date, focus only on the assessment of "poor welfare", as they quantify the occurrence of negative situations for the animals, for example, if the presence of the indicators (e.g., lameness) is frequent, the level of welfare is low and vice versa. However, a lack of perceived suffering does not guarantee that animals are experiencing a positive welfare state (Keeling et al., 2011; Mattiello et al., 2019). Positive welfare still remains difficult to define as it incorporates overlapping concepts, cultural preconceptions and individual ideas (Rault et al., 2020). In this context, the "Five Domains Model" provides a widely used theoretical framework for the integration of positive welfare in the assessment (Mellor et al., 2020). The model is comprised of four physiological/functional domains related to internal states and external circumstances (i.e., nutrition, environment, health and behavioural interactions) and a fifth domain (i.e., mental state). The fifth domain is a final component that shows positive or negative affective engagement resulting from the sum of internal and external circumstances from the other four physical/functional domains. This framework, though still improvable, moves the classical concepts of the four well-known welfare principles (i.e., 'Good feeding', 'Good housing', 'Good health', and 'Appropriate behaviour') (Botreau et al., 2009) one step forward, integrating the "mental state" domain.

To perform a true overall on-farm sustainability assessment, it would be desirable to consider both the farms' environmental impact and the welfare of the animals (Scherer et al., 2018; Broom, 2019; Tallentire et al., 2019). From an ethical and food safety point of view, it is fundamental to include animal welfare indicators as checkpoints of the production process. In fact, poor livestock welfare is not only related to ethically objectionable farming but is often associated with poor performance, health risks for livestock and humans, higher input use and non-optimised resource use efficiency, which directly affect the impact intensities of farming systems (Özkan et al., 2022). However, no clear mapping of the current literature is available to facilitate the creation of a framework which systematically integrates animal welfare into the farm sustainability assessment. Thus, considering (A) LCA as the most effective and standardised tool to assess the environmental impact of the agri-food sector, (B) the key role of animal welfare in livestock production and sustainability and (C) the absence of other reviews on such a topic, the aims of this Scoping Review were to (1) investigate the frameworks used in literature to assess simultaneously the environmental impact with LCA and animal welfare and (2) to map and categorise all the possible practical and theoretical approaches proposed in the literature to opportunely include animal welfare standards in the LCA of animal production processes. This literature mapping could serve as a starting point for the standardisation of the animal welfare-LCA integration, highlighting the strength and weaknesses of the assessment methods adopted by the different authors until now.

Material and methods

For the aim of the present work, a scoping review was considered to be an appropriate approach to focus on such a complex and under-investigated area (i.e., animal welfare-LCA integration), to summarise the methodologies adopted, to identify gaps in the research knowledge, and to clarify and report the methods adopted. Scoping reviews differ from traditional narrative and systematic reviews. These use a robust and systematical scheme (differently from the narrative reviews) to answer broad questions on under-investigated topics (differently from the systematic reviews which aim to answer clearly defined questions and provide robust ready-to-use guidelines (Grant and Booth, 2009). This type of reviewing approach is useful when the aim is to examine (1) the extent, range and nature of evidence on a topic, (2) summarise findings or methods from a heterogeneous body of knowledge, and (3) identify gaps in the literature to aid future research planning (Tricco et al., 2018). The protocol (available at https://doi.org/10.17605/OSF.IO/XMJ87) and the review itself followed the guidelines of the Joanna Briggs Institute (JBI) (Aromataris and Munn, 2020) and the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA-ScR) extension for scoping reviews (Tricco et al., 2018).

Research questions

The review was conducted following some specific primary (on the choice of indicators), secondary (on the context) and tertiary (on the results) research questions.

Primary questions (indicators): (1.1) Which animal welfare indicators were measured simultaneously with the environmental LCA evaluation? (1.2) Were these indicators integrated with the environmental impact assessment using an aggregated score or were they kept separate?

Secondary questions (context): (2.1) How many of the studies integrated an animal welfare protocol instead of just welfare indicators? (2.2) Which species were evaluated with this approach? (2.3) Where were those studies performed (geographical distribution)? (2.4) When were those studies performed (temporal distribution)? (2.5) Were other dimensions of sustainability (social, economic) evaluated in the selected studies?

Tertiary questions (results): (3.1) For the reviewed papers, is it possible to draw conclusions on the relationship between animal welfare and environmental sustainability?

Inclusion criteria

To identify the studies to include in this scoping review, the Population, Concept and Context (PCC) framework was followed. In particular, the included studies had to (1) focus on any animal species kept for production purposes and/or provide a theoretical framework, describing a methodology that could be then applied to that species; (2) comprise LCA as a methodology; (3) include at least one animal welfare indicator. The use of animal welfare indicators had to be specified by the authors since some could be collected routinely (e.g., mortality) to evaluate farm productive performances. If indicators were present, but no specific mention was given of their integration for animal welfare assessment, then those studies were excluded from the review. However, studies that proposed an LCA-based framework integrated with animal welfare, without directly evaluating the environmental impact, were included.

Studies using animal welfare to build scenarios with different environmental impacts were also excluded. This is because the review aimed to assess the methodological basis behind the possibility of the integration of these two aspects, and not specifically on how the variation of some specific indicators could reflect on the others. Only peer-reviewed studies written in English, Italian, French, Spanish or Portuguese were included. Congress abstracts and book chapters were not taken into consideration. No geographical or time limitations were applied during the searches.

Search strategy and source of evidence selection

The bibliographic research was conducted using Web of Science, PubMed, ScienceDirect and Scopus and selecting the "all fields" option. The keyword combinations used were as follows: ("LCA" OR "life cycle assessment") AND ("animal welfare" OR "livestock welfare" OR "poultry welfare" OR "welfare indicator"). No limitation was specified for the search, although only documents up to February 2022 were retrieved, as the search ended at that time. Once the search phase in all databases was completed, the identified citations were uploaded into a reference manager software, and duplicates were removed. References were then imported into Rayyan (Ouzzani et al., 2016), a web app that facilitates a collaborative review process. The final selection of studies was selected using three levels of screening: title and abstract screening, full text, and key study reference list. When articles were excluded, the reason for exclusion was noted. Once the study selection was completed in Rayyan, a report with all the information of the included papers was exported.

Data extraction

From the exported Rayyan file, relevant data from all articles were extracted to provide a logical summary related to the theme of the scoping review. The papers were classified according to the target of their research either as; "METHOD" when their main purpose was to develop a methodological framework to simultaneously assess animal welfare and LCA, "FARM" when their objective was to provide information on the sustainability of different farming systems, or "FOOD" when their purpose was to characterise food products and/or explain the theory behind consumer communication and information strategies.

Data concerning LCA and Animal Welfare were summarised. It was specified whether the welfare data were directly measured (recorded on-farm or from farm records) or estimated (taken from literature or national averages).

Furthermore, the animal welfare indicators used in each study were divided into the "5 Domains Model" (Mellor et al., 2020), considering the description of each domain. Specifically, (1) the 'Nutrition' domain refers to the availability and quality of water and feed and the access to a balanced diet for animals; (2) the 'Environment' domain refers to the physical and/or weather conditions to which animals are directly exposed; (3) the 'Health' domain refers to the animal welfare impacts of injury, disease and different levels of fitness; (4) the 'Behavioural Interactions' refers to behavioural outputs as indices of the animals' perceptions of their external circumstances and also includes animal-human interaction; (5) the domain 'Mental State' refers to the perception of the animal in relation to all stimuli received. The aim was to assess which of the five domains was evaluated by each author.

The studies were then grouped according to the tool used to assess animal welfare: single or multiple welfare indicators, validated or non-validated protocols or other methods. A "validated protocol" was defined as a well-known scheme for animal welfare assessment, which was structured by experts and published. When an animal welfare assessment scheme did not meet these requirements but allowed for the assessment of at least three domains and the criteria for the selection of indicators and the weight given to them were transparently specified, it was defined as a "non-validated protocol". When fewer than three domains were assessed and/or the criteria for selecting the indicators were specified, but the weight given to each indicator and their combination were not clearly stated, they were categorised as "multiple indicators". When animal welfare was described qualitatively or based only on expert evaluations, authors were classified as using "other methods".

Finally, the papers were grouped according to the method adopted to present a final animal welfare score. It was also noted which of the dimensions of sustainability the paper investigated (economic, social, and environmental) and whether animal welfare was included within the social dimension or not. Finally, the papers were grouped according to whether they proposed a final method to summarise the overall sustainability of the farms, with an "overall sustainability score" (including at least the environmental dimension and animal welfare), and ranked according to the methods used.

Results

The literature search resulted in 1 460 unique papers and, as shown in Fig. 1, the screening process resulted in a total of 24 papers that were considered consistent with the aim of this scoping review and research questions. The screening process, the exclusion reasons and some general details of the included papers (geographical location of the authors and year of publication) are reported in Fig. 1, Table 1 and Supplementary Material S1.

Aim of the studies and investigated farmed species

The target of the papers differed considerably, as summarised in Table 1: 12.5% (n = 3) mostly focused on providing a methodological framework (METHOD), 12.5% (n = 3) were oriented on explaining how information on food is delivered to consumers (FOOD), but most of the papers (75%; n = 18) aimed at assessing multidimensional sustainability across different farming systems (FARM) (Additional details in Supplementary Material S1). Among the included papers, six studied dairy cows, five broiler chicken farms, four pig production, two laying hens and one sheep farming (Supplementary Fig. S1).

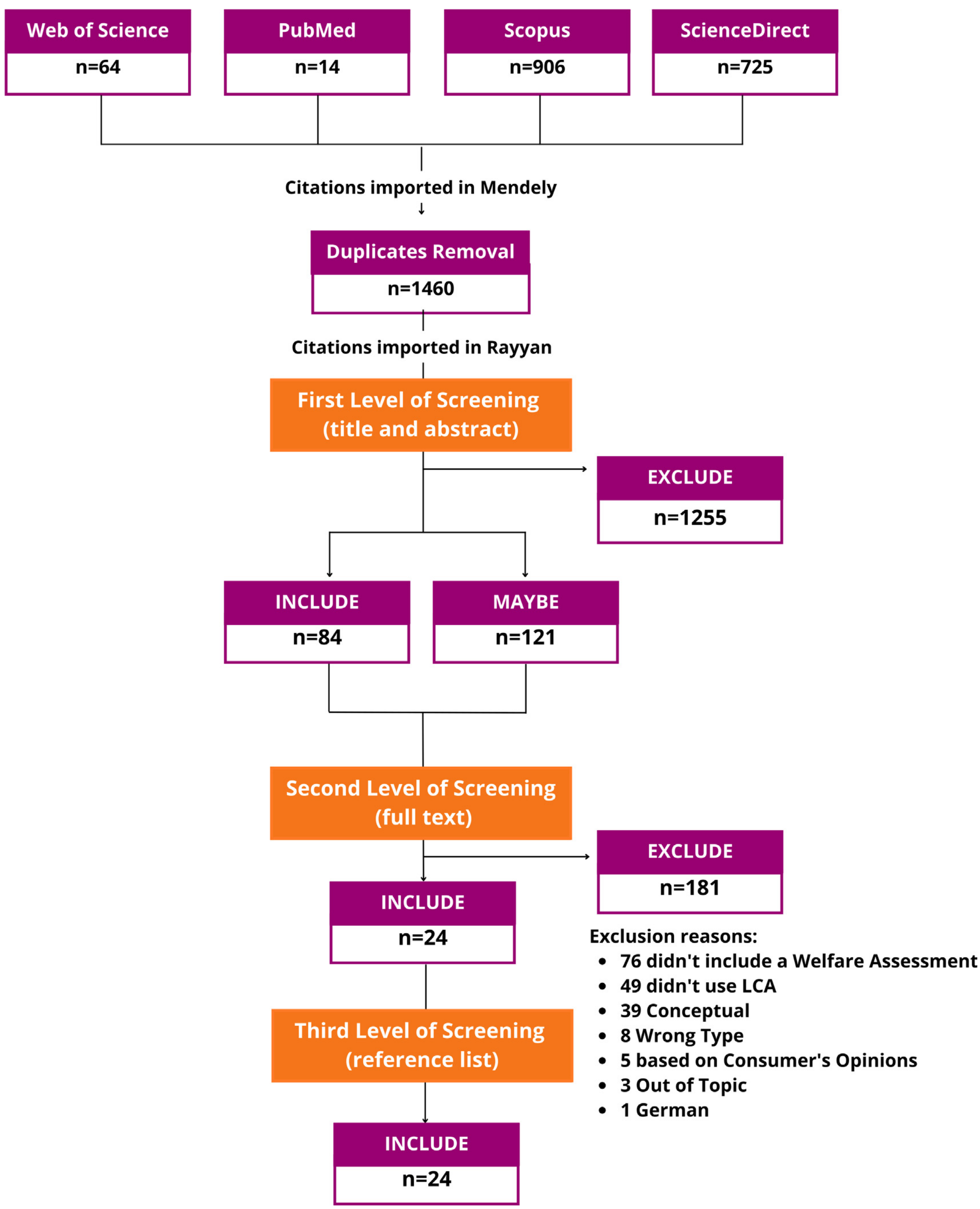

Fig. 1. Flow diagram of the reviewing process of the published studies comprising animal welfare evaluation and Life Cycle Assessment on production animal species. Abbreviation: LCA = Life Cycle Assessment.

Table 1
Country, target, livestock species, functional unit and system boundaries adopted in the papers included in the review.

Authors	Country	Target	Species	Functional Unit	Boundaries
Boggia et al. (2019)	IT	Farm	Broiler chickens	1 kg of meat	from cradle to farm gate
Bonneau et al. (2014)	MEC	Farm	Pigs	1 kg of LW + 1 ha of land used for pig production	from cradle to farm gate
Castellini et al. (2012)	IT	Farm	Broiler chickens	1 kg of meat	from cradle to farm gate
Dolman et al. (2012)	NL	Farm	Pigs	1 kg of SW	from cradle to farm gate
Dolman et al. (2014)	NL	Farm	Dairy cows	1 kg of FPCM	from cradle to farm gate
Geß et al. (2020)	IT	Farm	Sheep	1 kg of meat	from cradle to farm gate
Haas et al. (2000)	DE	Method	Framework for Haas et al. (2001)		from cradle to grave
Haas et al. (2001)	DE	Food	Dairy cows	1 ha + 1 tonne of milk	from cradle to grave
Head et al. (2014)	NL	Food	Protein-rich food	1 kg of product	from cradle to retail
Mas et al. (2016)	ES	Farm	Dairy cows	1 kg of FPCM	from cradle to farm gate
Mollenhorst et al. (2006)	NL	Farm	Laying hens	1 kg of eggs	from cradle to farm gate
Müller-Lindenlauf et al. (2010)	DE	Farm	Dairy cows	1 kg of milk + 1 000 kg of milk + 1 ha of farmland	from cradle to farm gate
Petit et al. (2018)	FR	Method	Case study on Pigs	1 kg of cooked ham produced in 1 year by the farm	from cradle to farm gate
Rocchi et al. (2019)	IT	Farm	Broiler chickens	1 kg of meat	from cradle to farm gate
Rocchi et al. (2021)	IT	Farm	Broiler chickens	1 kg of meat	from cradle to farm gate
Röös et al. (2014)	SE	Food	Meat products and eggs	1 kg of product	from cradle to retail
Scherer et al. (2018)	NL	Method	Case study on various animal species	1 Mcal	from cradle to retail
Tallentire et al. (2019)	MEC	Farm	Broiler chickens	1 kg of meat	from farm to the slaughter
Van Asselt et al. (2015a)	NL	Farm	Dairy cows	1 kg of FPCM	from cradle to grave
Van Asselt et al. (2015b)	NL	Farm	Laying hens	1 kg of eggs	from cradle to farm gate
Ziegler et al. (2021)	GL	Food	Meat products	1 kg of meat	from hunting to transport/from cradle to farm gate
Zira et al. (2020)	SE	Farm	Pigs	1 000 kg of meat at the consumers' fork	from cradle to the consumer
Zira et al., (2021)	SE	Farm	Pigs	1 000 kg of meat at the consumers' fork + 1000 ha of farmland	from cradle to the consumer
Zucali et al. (2016)	IT	Farm	Dairy cows	1 kg of FPCM	from cradle to farm gate

Abbreviations: NL = The Netherlands; IT = Italy; DE = Germany; FR = France; MEC = multiple European countries; ES = Spain; SE = Sweden; GL = Greenland; LW = live weight; SW = slaughter weight; FPCM = fat and protein corrected milk.

Life Cycle Assessment characteristics

The functional unit **(FU)** is the reference unit for the impact categories assessed with LCA and, varied in relation to the aim of the studies and the species assessed (Table 1).

The boundaries used in the LCA evaluation were mostly "from cradle to farm gate" (n = 14) as shown in Table 1, while other approaches were adopted with lower frequencies: "from cradle to consumer" (n = 2), "from cradle to grave" (n = 3), "from cradle to retail" (n = 3). Ziegler et al. (2021) used two system boundaries, "from hunting to transport" and "from cradle to farm gate" since the aim was to compare seal meat derived from hunting with commercial pork and poultry meat.

As described in Supplementary Table S1, the methodological choices used for the calculations were quite heterogeneous and a lack of completeness in the representation of the available environmental impact categories for the farming systems is clear. Specifically, all the papers assessed the climate change impact category (or global warming potential), followed by the acidification potential (75% of the papers), land use (75% of the papers) and eutrophication potential (70% of the papers). Other impact categories were found to be assessed with a lower frequency.

Animal welfare characteristics

In thirteen of the studies, the animal welfare indicators were measured directly on the farm or collected from farm registers or databases that gathered farm-specific data. In contrast, in nine of the studies, the indicators were 'estimated', i.e., taken from literature or national averages, or from the perception of experts and therefore not directly related to a specific farm. In two of the cases (Haas et al., 2000; Petit et al., 2018), the animal welfare indicators were neither measured nor estimated, as only a framework or example of application was presented without data collection.

Domains framework: domains assessed

Of the 24 papers, 29.2% of the studies (n = 7) took into account just one domain, six of the studies (25%) evaluated two domains, five studies (20.8%) took into account three domains, three (12.5%) of the studies evaluated four domains, while no studies took into account all the five domains (Supplementary Fig. S2 and Table 2). It was not possible to classify three of the papers with the domain's framework due to the lack of information on the indicators selected for the animal welfare evaluation, or because those were discussed qualitatively. In general, the environment domain was the most frequently assessed (n = 19), followed by health (n = 11) and nutrition (n = 7). The most neglected domains were especially, mental state (n = 2) but also behavioural interactions (n = 6) as can be seen in Table 2.

Animal welfare indicators evaluated

The choice of animal welfare indicators varied between studies (Supplementary Table S2). The most used indicators were the proportion of drinkers/feeders in relation to the number of animals and their cleanliness for the domain "nutrition", access to pasture, grazing time or stocking density for the domain "environment", mortality for the domain "health" and some behavioural indicators (i.e., kinetic activity) for the "behavioural interaction" domain. The heterophil/lymphocyte ratio and the cortisol concentration were used to assess the "mental state" domain. The revised papers were grouped according to the type of animal welfare assessment carried out: with a single indicator, multiple indicators, validated pro-

Table 2
Number and type of Welfare Domains assessed by each paper included in the review for production animal species.

Authors	5 Welfare Domains				
	Nutrition	Environment	Health	Behavioural Interactions	Mental State
Boggia et al. (2019)		✓	✓		
Bonneau et al. (2014)	✓	✓	✓	✓	
Castellini et al. (2012)		✓		✓	✓
Dolman et al. (2012)			✓		
Dolman et al. (2014)		✓			
Geß et al. (2020)					✓
Haas et al. (2000)		✓			
Haas et al. (2001)		✓			
Head et al. (2014)	NA	NA	NA	NA	NA
Mas et al. (2016)					
Mollenhorst et al. (2006)	✓	✓	✓		
Müller-Lindenlauf et al. (2010)	✓	✓	✓		
Petit et al. (2018)		✓		✓	
Rocchi et al. (2019)		✓		✓	
Rocchi et al. (2021)		✓		✓	
Röös et al. (2014)		✓			
Scherer et al. (2018)		✓			
Tallentire et al. (2019)		✓	✓		
Van Asselt et al. (2015a)	✓	✓	✓		
Van Asselt et al. (2015b)		✓	✓		
Ziegler et al. (2021)	NA	NA	NA	NA	NA
Zira et al. (2020)	✓	✓	✓	✓	
Zira et al., (2021)	✓	✓	✓	✓	
Zucali et al. (2016)	✓	✓	✓		

Abbreviations: NA = when it was not possible to classify the work in the five domains framework.

tocols, non-validated protocols or other methods. When multiple indicators were used, clustering within the assessed species was carried out to enhance clarity.

Single animal welfare indicator: In four of the selected studies, a single indicator was evaluated. Geß et al. (2020) used lamb's hair cortisol concentration to compare animal welfare among different rearing systems (semi-intensive VS semi-extensive). Grazing time for dairy cows and mortality rate for pigs were selected as welfare indicators by Dolman et al. (2012) and (2014), respectively. Scherer et al. (2018) presented a framework and a case study on various animal species, using a single indicator of the domain "environment" for each species (i.e., days on pasture for ruminants, surface available for pigs and stocking density for poultry and fish). Multiple animal welfare indicators: In eleven studies, several welfare indicators (reported in detail in Supplementary Table S2) were assessed simultaneously and summarised below in the respective evaluated species.

Dairy cows: Haas et al. (2001) and Zucali et al. (2016) (following the framework of Haas et al. (2000)) evaluated animal welfare in dairy cows using multiple indicators. However, while Zucali et al. (2016) used indicators related to three animal welfare domains ("nutrition" = Body Condition Score; "environment" = claw overgrowth and "health" = diarrhoea and lameness), Haas et al. (2001) did not clearly specify the indicators used. The only information provided was that the indicators were related to farming conditions and were taken from the TGI-200 (Sundrum et al., 1994), so it can be assumed this was assessing the domain" environment" only.

Pigs: Petit et al. (2018) proposed a framework to integrate the measurement of some indicators that could reflect the "environment" and "behavioural interaction" domains, i.e., the maximum duration of transport without pauses to which animals are subjected and the pH of the meat. In particular, the latter could be an indicator of the correct handling of the animals during transport and at the slaughterhouse.

Broiler chickens: Five studies used multiple indicators to evaluate animal welfare in broilers. All studies used one or more indicators related to the domain "environment", i.e., the % of footpad lesions (Castellini et al., 2012; Boggia et al., 2019; Rocchi et al., 2019; 2021), the % of breast lesions (Castellini et al., 2012; Rocchi et al., 2019; 2021), stocking density (Rocchi et al., 2019; Tallentire et al., 2019) and the use of pasture (Rocchi et al., 2019; 2021). Indicators associated with the domain "behavioural interactions" were used by three of the papers (Castellini et al., 2012; Rocchi et al., 2019; 2021) which specifically monitored the general kinetic activity of the animals during their last week of life. The "health" domain-related indicators used were collected either on farm or at the slaughterhouse by Boggia et al. (2019) and Tallentire et al. (2019) who both monitored the mortality rate on-farm. Tallentire et al., (2019) also monitored the % of dead-on-arrival and the % of condemned carcasses at the slaughterhouse. The "mental state" domain was only assessed by Castellini et al. (2012), who monitored the heterophil/lymphocyte ratio of a cluster of animals as an indicator of stress to compare different farming systems (conventional vs organic vs organic plus).

Laying hens: Van Asselt et al. (2015b) used the space availability (domain "environment") and the mortality rate ("health" domain) to assess the animal welfare of laying hens kept under different housing conditions (enriched cages vs barn vs free-range vs organic).

Various animal species: Röös et al. (2014) considered livestock systems focusing on meat and egg production (pigs, beef cattle, broilers and laying hens) as the best for animal welfare when they allowed access to grazing (domain "environment") and were compliant with the Swedish (or equivalent) animal welfare legislation.

Validated protocols: Mollenhorst et al. (2006) and Van Asselt et al. (2015a) used existing and validated protocols for laying hens (TGI-200, (Sundrum et al., 1994)) and dairy cows (TGI-35L, Bartussek, 1995), respectively. Both protocols were mostly focused on the domain of "nutrition" and "environment" but, while in TGI-35L, an overall assessment of the general health of the animals was already included, in TGI-200, it was not present. Therefore, to overcome this limitation, Mollenhorst et al. (2006) added some aggregated indicators to the adopted protocol to assess the health status of the hens, and thus the "health" domain.

Non-validated protocols: Bonneau et al. (2014), Zira et al. (2020) and (2021) used non-validated protocols to assess the animal welfare of pig farms in different systems covering four of the five animal welfare domains (''nutrition'', ''environment'', ''health'', ''behavioural interactions''). An assessment of dairy farms was performed by Müller-Lindenlauf et al. (2010) with a protocol that included the ''nutrition'', ''environment'', and ''health'' domains. Further details are reported in Supplementary Table S1.

Other methods: Ziegler et al. (2021) estimated animal welfare qualitatively from literature data (without specifying the criteria used), considering the suffering during the killing of seals or slaughtering of other animals to produce Danish pork and poultry meat. Head et al. (2014) assessed the welfare of various farming systems based on a questionnaire submitted to experts in the field of animal husbandry and behaviour; therefore, the welfare evaluation was based on the perception of experts. Mas et al. (2016) performed an animal welfare assessment using an index, without specifying the indicators included in this evaluation.

Aggregation for animal welfare evaluation

Once the animal welfare data were collected, some of the papers presented them in an aggregated form (n = 16), as can be seen in Table 3. This aggregation can be helpful to get an idea of the welfare level of the system studied or for comparing different production systems.

Animal welfare related to the functional unit: Four papers provided an aggregation of animal welfare indicators that resulted in a score based on the functional unit, the unit of measurement used by LCA (Scherer et al., 2018; Tallentire et al., 2019; Zira et al., 2020; 2021). Tallentire et al. (2019), Zira et al. (2020) and (2021) followed the United Nations Environment Programme, (2009) guidelines for social life cycle assessment and provided a framework for including pigs as stakeholders in the social assessment. In particular, Zira et al. (2020) used Social Risk (**SR**), Social Risk Time (**SRT**) and Social Hotspot Index (**SHI**) as final aggregated animal welfare indicators, Zira et al. (2021) the SRT and Tallentire et al. (2019) the SHI and the Animal welfare impact (**AWI**), which is similar to the SRT. On the other hand, Scherer et al. (2018) proposed three different indicators: Animal life years suffered (**ALYS**), loss of animal lives (**AL**), and loss of morally adjusted animal lives (**MAL**).

Animal welfare scale: Ten papers provided an animal welfare aggregation in the form of a scale/rating. The ranking scale and the methods to obtain it were heterogeneous, possibly because the type and the number of animal welfare indicators evaluated differed significantly between studies.

Traffic light signs: Röös et al. (2014) and Ziegler et al. (2021) used a traffic light performance system to provide information on animal welfare. The highest animal welfare score (green) was given if it was possible for the animals to access grazing and if the farm was following the Swedish or equivalent animal welfare legislation (Röös et al., 2014). On the other hand, Ziegler et al. (2021) categorised the animal welfare level qualitatively (supported by literature evidence), considering the suffering the animals must face during their life and, killing or slaughtering.

For a more detailed description of the aggregation of animal welfare indicators, see Supplementary Material S1.

Table 3

Aggregation systems of welfare indicators and overall sustainability evaluation approaches adopted in the papers included in the review for production of animal species.

Authors	Animal Welfare evaluation			Overall Sustainability evaluation	
	Aggregation	Unit of measurement	Relation with FU	Type	Weighing method
Boggia et al. (2019)	No		No		
Bonneau et al. (2014)	Animal welfare scale	0–1 (best)	No	Theme score + Overall index	equal
Castellini et al. (2012)	No		No	MCDA	stakeholders
Dolman et al. (2012)	No		No	Overall index	equal
Dolman et al. (2014)	No		No		
Geß et al. (2020)	No		No		
Haas et al. (2000)	Provides the framework for Haas et al. (2001)				
Haas et al. (2001)	Animal welfare scale	1 (very good) – 5 (unsatisfactory)	No		
Head et al. (2014)	Animal welfare scale	0–10 (best)	No	Overall index	equal
Mas et al. (2016)	Animal welfare scale	0–100 (best)	No		
Mollenhorst et al. (2006)	Animal welfare scale	Score for each category of the TGI-200 + average values of other indicators	No		
Müller-Lindenlauf et al. (2010)	Animal welfare scale	0–10 (best)	No	Overall Index	equal
Petit et al. (2018)	No		No		
Rocchi et al. (2019)	No		No	MCDA	stakeholders
Rocchi et al. (2021)	No		No	MCDA	equal
Röös et al. (2014)	Traffic light system	From green to red	No		
Scherer et al. (2018)	Animal life years suffered, Loss of animal lives, Loss of morally adjusted animals' lives	n of years, n of animals (including or not the moral value of lives)	Yes		
Tallentire et al. (2019)	Animal welfare risk, Social hotspot index	Medium risk hour equivalent, 0–1	Yes		
Van Asselt et al. (2015a)	Animal welfare scale	1–45.5 (<11 not sufficient)	No	Overall index	experts
Van Asselt et al. (2015b)	Animal welfare scale	0–100 (best)	No	Overall index	experts
Ziegler et al. (2021)	Traffic light system	From green to red	No		
Zira et al. (2020)	Social risk, Social risk time, Social hotspot index	0–1, risk pig life days, 0–1	Yes		
Zira et al., (2021)	Social risk time	Risk pig life days	Yes	Relative sustainability points	
Zucali et al. (2016)	Animal welfare scale	0–3 (best)	No	Overall index (Process and Product quality)	equal

Abbreviations: TGI-200 = Tiergerechtheitsindex-200 protocol by Sundrum et al. (1994); FU = functional unit; MCDA = multi-criteria decision analysis.

Overall sustainability evaluation

Sustainability dimensions evaluated and animal welfare inclusion

As shown in Supplementary Table S3, the most frequently assessed sustainability dimension was environmental (20 papers), while the social and the economic dimensions were assessed in 13 and 14 papers, respectively. In eleven papers, all three dimensions were assessed, in three, only two dimensions were mentioned (environmental and economic), and in nine papers, only one dimension was considered (Supplementary Fig. S3 and Supplementary Table S3). Of these nine papers, most authors (77.8%; n = 7) assessed the environmental dimension, while two assessed only the social aspect. This subdivision raises an interesting question about the role of animal welfare within these dimensions, as there is much debate on the subject, and it is difficult to give a clear answer. Regarding animal welfare, 42% (n = 10) of the articles included it in the social dimension, while the rest did not include it in any dimension (Supplementary Table S3).

Overall sustainability score

Eleven papers provided an overall sustainability score, obtained using different methods. This approach was mostly used to provide a final ranking or to allow comparison among different farming systems. The methods used were grouped as follows: methods to perform a relative comparison, overall indexes obtained by equal weighting or by expert-weighting and multi-criteria decision analysis obtained by equal weighting or by stakeholder-weighting (Table 3).

Methods to perform a relative comparison: Zira et al. (2021) used Relative Sustainability Points as a method to perform a comparison between the two farming systems studied (organic vs conventional). This method is useful to perform a relative comparison between two studied situations; therefore, the aim was not to provide an overall score but to understand the relative differences.

Overall indexes: Several authors provided an overall index (either for each sustainability dimension assessed and/or for the overall assessment). The main differences between the authors were the scoring scales (0–10, 0–100, from −1 to +1) and the methods for weighting the different indicators and dimensions when aggregating them. Specifically, Müller-Lindenlauf et al. (2010), Head et al. (2014), Bonneau et al. (2014), Dolman et al. (2012) and Zucali et al. (2016) used an equal weighting approach, while Van Asselt et al. (2015a) and (2015b) adopted an expert-weighting approach.

Multi-criteria decision analysis: Castellini et al. (2012), Rocchi et al. (2019) and (2021) used a multi-criteria decision analysis (MCDA) method to perform the overall assessment. In particular, "Electre I" was the method used by Castellini et al. (2012) and "PROMETHEE I and II" by Rocchi et al. (2019) and (2021). Both methods are useful for decision-making and are based on a pairwise comparison of two alternatives with a final aim to provide a ranking for a specific issue. This approach can be used to compare different farming systems. However, to perform an overall sustainability ranking, a weight must be attributed to each of the dimensions or themes analysed. In this respect, Rocchi et al. (2021) used equal weighting, while Castellini et al. (2012) and Rocchi et al. (2019) adopted a stakeholder opinion-based weighting approach.

Additional details on methodologies summarised in this section are provided in Supplementary Material S1.

Discussion

This scoping review is, to our knowledge, the first to describe and summarise evidence presenting a simultaneous assessment or framework to combine animal welfare measurement and environmental impact evaluation with Life Cycle Assessment. The importance of these issues is undeniable as both represent a fundamental component of the quality of the animal production chain (Zucali et al., 2016) and both are related to the management choices of the farmers. This type of approach can bring benefits on several fronts, in particular to the world of research and policy-making.

Implications for research

Despite the importance of these issues, a low number of authors have adopted such a combined approach (n = 24). The results highlight how the assessment of environmental sustainability (with LCA) seemed to be undertaken with a much more homogenous and standardised method than animal welfare assessment. The variability found in the methodological choices of LCA in terms of system boundaries and FU was mainly related to the objective of the different papers reviewed and to the differences in target species (e.g., all studies that assessed the environmental impact of dairy farms used 1 kg of milk as FU). However, some harmonisation is still needed, especially regarding the methodological choices for the calculations and the impact categories assessed. In fact, this review confirms the need to adapt the LCA to be more comprehensive in the selection of impact categories, to better, and more homogeneously represent the various nuances that characterise the farming systems (Notarnicola et al., 2017; Van der Werf et al., 2020). When considering animal welfare assessments, high variation was found in the selected indicators, even within the same animal species. Interestingly, although validated protocols are available to perform on-farm welfare assessments, those were adopted in only two of the studies included in this review: i.e., the TGI35-L by Mollenhorst et al. (2006), and the TGI-200 by Van Asselt et al. (2015a). Those protocols, although now dated, are robust, widely recognised and have laid the foundation for the development of subsequent methods. However, their limit is to mostly include indicators based on resources and management, or else, they are mainly focused on the "nutrition" and "environment" domains, with some attempts to comprise some "health" indicators. Therefore, they do not consider two other aspects that are crucial for a comprehensive assessment of animal welfare, namely "behavioural interactions" and "mental state". Regarding the "mental state", it was found to be the most neglected domain in the reviewed studies and the biological indicators used to assess it (i.e., cortisol level and heterophil/lymphocyte ratio) do not allow a comprehensive evaluation. The variation of both parameters can reflect a stressful situation that the animal has to face which disrupts homeostasis, but it does not give any information on the type or valence of the stimuli: as it can either be positive or negative (Broom, 2017; Skwarska, 2019). Although these indicators were not conceived to assess the 'mental state' of animals, they are the closest to this purpose among the papers included in the present review. The identification of the large admission of mental state allows for reflection on the need to adopt further indicators that could allow for a comprehensive assessment of this domain. For example, the qualitative assessment of behaviours (QBA), included in the AWIN (European Commission, 2022a) and Welfare Quality® (Botreau et al., 2009) protocols, (never adopted by the papers included in this review), is one approach for its assessment but requires training of assessors (Fleming et al., 2016).

However, it is clear from the results of this review that most studies used single (n = 4) or aggregated indicators (n = 11), non-validated protocols (n = 4), or qualitative methods (n = 3) to assess welfare. The choice of animal welfare indicators is crucial: the indicators selected must have been proven scientifically valid and be able to cover its multidimensionality (EFSA Panel on Animal Health and Welfare, 2012). The results of this review identify that one of the highest risks is that the welfare indicators that are selected actually reflect the researcher's idea of welfare, rather than the real welfare state of the animals (Spoolder et al., 2003; Browning, 2022). For example, Scherer et al., 2014, proposed the "Animal Life Years Suffered" as a novel indicator of welfare (related with the FU). This indicator is calculated considering the "life quality of the animals", which depends on different factors in relation to the species evaluated; for dairy cows, the parameter considered is the number of days spent at pasture. Röös et al., (2014) in a similar way uses the access to pasture (and the compliant with the Swedish legislation) as the only indicator to upgrade welfare as "green" with a traffic light scoring system. Although the access to pasture is a parameter recorded in animal welfare protocols, it is not sufficient to guarantee an improved welfare situation for animals (Schulte et al., 2018) as it may represent more an ethical judgement of the researcher rather than a scientific criterion to demonstrate a better state of animals. Another example is the use of the meat pH and the transport time without a break as indicators of welfare for pigs, as proposed by Petit et al. (2018). Both indicators can be useful to collect information on how the pigs were handled during the transport to the slaughterhouse (Cobanovic et al., 2021; Nielsen et al., 2022), but are not sufficient to provide a comprehensive evaluation. Similarly, the animal welfare assessment based on personal perception or interpretation (Head et al., 2014; Ziegler et al., 2021) is not only scientifically flawed but also can lead to ambiguous results, causing disinformation to the consumers. Moreover, considering animal welfare as a multidimensional concept (EFSA Panel on Animal Health and Welfare, 2012), the use of a single indicator for its assessment (Dolman et al., 2012 and 2014; Scherer et al., 2018; Geß et al. 2020) is not adequate to represent the complexity and the nuances of the five domains.

The results of this study show that only one (n = 7), two (n = 6) or three (n = 5) domains of animal welfare were assessed simultaneously; no papers in this review attempted to address all of the five animal welfare domains in relation to sustainability. As also recommended by EFSA, an appropriate holistic approach, that captures all these nuances should be preferred, as incomplete evaluations could lead to misleading conclusions (Mason and Mendl, 1993; EFSA Panel on Animal Health and Welfare, 2012).

The results show, depending on the aim of the studies, that the animal welfare indicators included in these papers were directly measured (n = 13) or estimated (n = 9). While the direct measurement of indicators is essential when the aim is to compare or highlight the situation of a specific farm, collecting data from the literature may cause difficulty in noticing variations between different systems.

Regarding the aggregation of welfare indicators, each method carries with it some advantages and disadvantages, and inevitably involves some degree of human judgement (Spoolder et al., 2003), especially when a weight is attributed to each indicator (Sandøe et al., 2019). The perception of the importance and meaning of animal welfare may vary among the stakeholders considered (Spoolder et al., 2003;), so its assessment is based on opinions (Head et al., 2014) or the weighting of indicators by a panel of experts (Zira et al., 2020) may not represent the real condition of the animals in the farm, thereby under or overestimating their welfare. As the aggregation of the indicators can have important repercussions, as it might involve controversial ethical, moral, and political decisions, transparency in the description of the method adopted is required (Spoolder et al., 2003).

The use of international standard rules, such as Product Category Rules (EPD International AB, 2022), used for LCA, could be considered also to provide guidelines for the animal welfare assessment and scoring. For example, a list of minimum requirements and indicators to be used in the different species for a complete welfare assessment would be extremely useful to improve the comparability among estimates. This type of framework could enable a more standardised process of integration of animal welfare with LCA.

Furthermore, the results highlight how one of the major challenges, when it comes to integrating animal welfare into LCA, is the ability to use the same unit of measurement (or FU) for all impacts and issues assessed (Broom, 2019). Some authors provided solutions on how to overcome this limitation (Scherer et al., 2018; Tallentire et al., 2019; Zira et al., 2020; 2021). However, these proposed indicators come from a complex process of indicator selection and weighting that requires a wider application in future research to make it reliable and multi-species adaptable.

Even though it was out of the scope of this review to discuss exhaustively sustainability in general, the reviewed papers were considered from the classical three dimensions definition of sustainability (environmental, social, economic). In this context, it was evident how the environment was the most assessed dimension of sustainability (n = 21), while the economic (n = 14) and social (n = 13) dimensions were less frequently addressed, and only a few studies evaluated all three dimensions simultaneously (n = 11), all of which agrees with other discussions accentuating these point by Gunnarsson et al. (2020). When multiple aspects of sustainability are evaluated, it is helpful to provide a single key of interpretation (such as an overall sustainability score), especially when this information needs to be conveyed to different stakeholders and used for decision-making processes of potentially already scarce resources. The use of overall sustainability indexes implies a huge compression of information into a single or a small number of indicators that brings with it a wide range of uncertainties and choices (Arulnathan et al., 2020). As discussed for the aggregation of animal welfare indicators, when a weight is attributed to each indicator by a group of experts, or stakeholders (Castellini et al., 2012; Van Asselt et al., 2015b and 2015a; Rocchi et al., 2019), the confidence of the results could be questionable, since it is inherently a social, political and ethical evaluation (Arulnathan et al., 2020). In addition, this procedure is usually very complex to perform and takes a long time to produce results (Lampridi et al., 2019). On the contrary, the equal weighting could be as problematic since it places all the addressed issues on the same level since this assumption reflects the researcher's concept of sustainability rather than the tool, users, and the stakeholders (animals, farmers, consumers, etc.), to whom this message could be delivered (Lampridi et al., 2019). In this framework, multi-criteria decision analysis (**MCDA**) (Castellini et al., 2012; Boggia et al., 2019; Rocchi et al., 2019; 2021) was suggested as a good method to help researchers in dealing with subjective assumptions objectively, whilst also taking into consideration stakeholders' values, and could be further explored as an option for aggregating results across several impact categories (Arulnathan et al., 2020). Despite the approach taken, it is important to be transparent in the choices and to provide a detailed description of how indicators are eventually normalised and weighted (Arulnathan et al., 2020), especially if it is a two-stage aggregation (animal welfare score and overall sustainability score). More participatory methods and systems modelling techniques may also help with tackling such complexities.

In this context, an attempt to summarise the results of the papers included in this review was made to understand the relationship between environmental sustainability and animal welfare. As it can be seen from Supplementary Table S4, it was not possible to give a clear answer to this question, mostly due to the methodological differences among studies. Therefore, it becomes essential to provide adequate inclusive tools to evaluate this relationship and identify real win–win mitigation solutions (Broom, 2019).

This review highlights how the scientific community should (1) focus on providing guidelines on the minimum number of scientifically validated indicators that should be used to perform a comprehensive welfare assessment in each animal species; (2) continue research on species-specific indicators related to all five animal welfare domains, if missing, with a particular focus on indicators that assess the "mental state" domain; (3) promote the development and use of the Standard Category Rules for the assessment of agricultural systems; (4) promote comprehensive LCAs, which take into account a set of complete impact categories to accurately represent agricultural systems; (5) continue investigations on finding a robust way to integrate Animal welfare in LCA for all the species, providing transparent guidelines; (6) prioritise direct on-farm data collection of information when the aim is

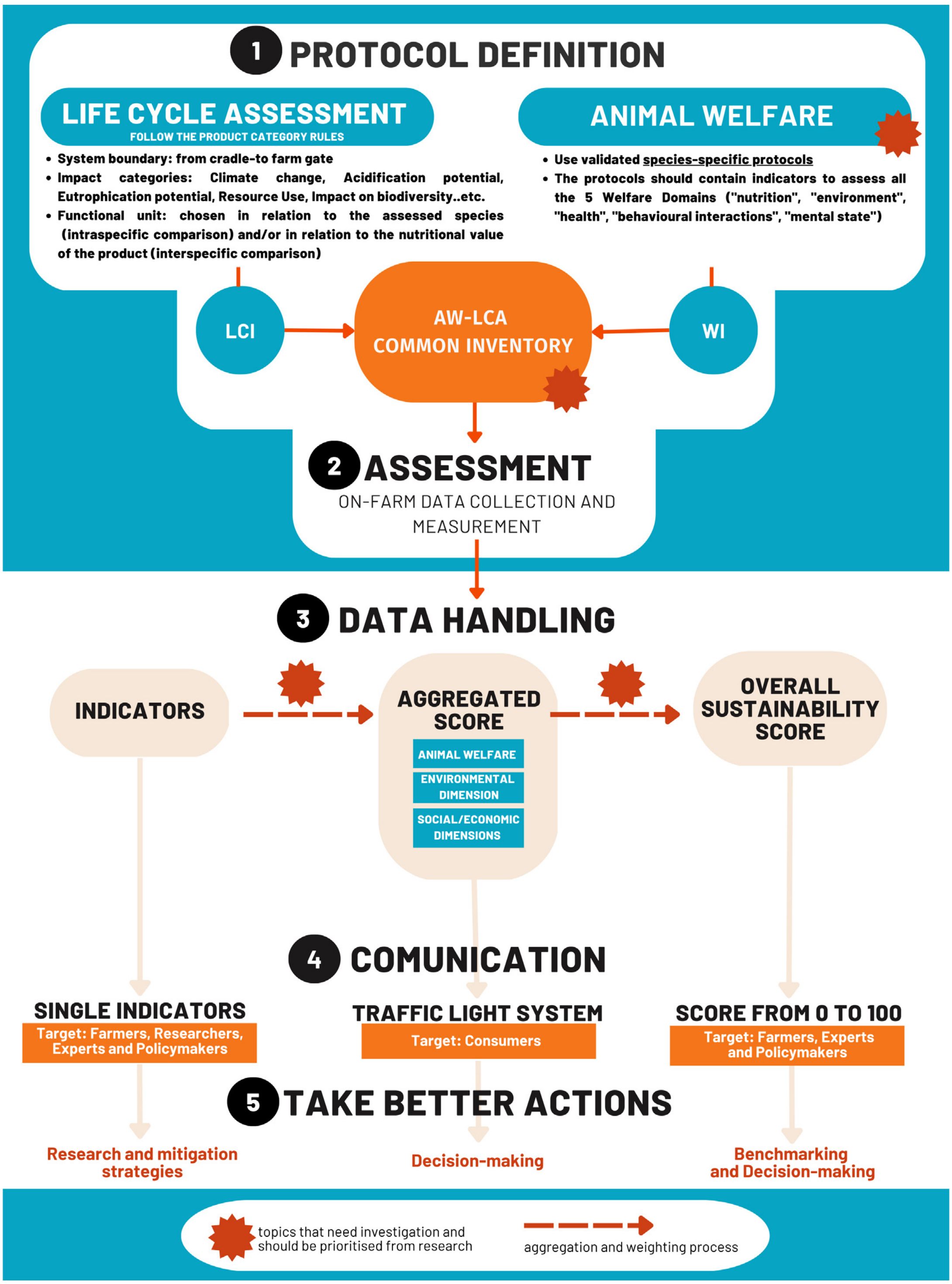

Fig. 2. Brief practical proposal for animal welfare-Life Cycle Assessment integration for a holistic sustainability assessment in production animal species: how to move forward. Abbreviations: AW = animal welfare; LCA = Life Cycle Assessment; LCI = life cycle inventory; WIs = welfare indicators; Common AW-LCA inventory: a common checklist for the collecting data for LCA and animal welfare assessment.

to investigate farm sustainability; (7) be transparent and consistent in the choice and aggregation of indicators in overall animal welfare and sustainability indexes. Considering the current state of knowledge, several limitations of both LCA and Animal welfare assessment need to be overcome before reaching a robust integration. In any case, this process is currently ongoing, and this review can serve as a starting point for future research and assessment.

In particular, a suggestion of a practical proposal for animal welfare-LCA integration derived from the analysis carried out in this scoping review is presented in Fig. 2. Briefly, we suggest performing LCA following the Product Category Rules (when available) and using validated protocols to measure animal welfare on-farm. For the on-farm data collection, we propose to build a common checklist (AW-LCA common inventory) containing all the information related to animal welfare and to environmental assessment. We also suggest that the data should be handled according to the aim of the assessment: use a single indicator if the aim is research or finding mitigation strategies (target: farmers, researchers, experts, policymakers), use traffic light systems of the different sustainability dimensions and welfare to help consumers in the decision-making process, use overall sustainability scores when the aim is benchmarking (target: farmers, experts) and decision-making (target: policymakers).

Implications for policy

Animal welfare and sustainability are acknowledged as priorities for the resilience of farming systems by the European Commission (European Commission, 2020), FAO, WHO and OIE (FAO-OIE-WHO, 2022; Keeling et al., 2019).

The roadmap has been set, and it has been recognised how animal welfare requirements will impact the sustainability of farming and food production. Moreover, it is expected that increasing the consumer knowledge of the EU's sustainable production methods will improve the market position of products respecting animal welfare. This could be achieved by label schemes to empower consumers to make informed choices and will have an impact on animal welfare protection and sustainability at the same time (European Commission, 2020 and 2022b).

Therefore, the development of guidelines to perform a combined animal welfare-LCA evaluation in a robust way is crucial, since (1) it could contribute to providing evidence-based data, (2) it could facilitate taking decisions in the policy-making process, (3) it could help to better understand and include the complexity of the problem, (4) it could help in targeting the priorities of interventions for environmental impacts mitigation actions and for improving animal welfare (Llonch et al., 2017) and (5) could help in simplifying the process of the development of schemes of welfare and sustainability certifications and labelling of animal-derived food products.

Limitations of the study

Although this review was conducted according to the scoping review methodologies and guidelines, there were some limitations that are worth noting. (1) Papers adopting other kinds of environmental assessment methods than LCA were excluded. These criteria could have underestimated the number of pieces of evidence; however, LCA was chosen as the gold standard methodology; (2) Grey literature was not included in this review as authors considered it appropriate to only include papers that had been peer-reviewed; (3) This field of research and development is growing, so the review can only be a snapshot of the time in which it was written.

Conclusions

This review summarises all the papers that, to date, used or proposed an approach to integrate animal welfare with Life Cycle Assessment. As shown in the results, there is no consistency in the standardisation of this integration, starting with the selection of welfare indicators and ending with the weight given to aggregate them. This is probably because animal welfare and sustainability are complex and multidimensional topics, infused with ethical and social implications. This challenge can be met by emphasising multidisciplinarity through the increased collaboration of experts in animal welfare and LCA. Given the pressing nature of the issues, in order to carry out a comprehensive, true-to-life and robust farm sustainability assessment, it is essential to develop guidelines to ensure that approaches are standardised, and the results of this review will help during this development process.

Supplementary material

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Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository. No new datasets were created.

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Declaration of interest

None.

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