





Review

Systematic Mapping of Research on Farm-Level Sustainability in Egg and Chicken Meat Production

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Abstract: The sustainability of future poultry production needs to be improved in order to meet global challenges. The global chicken population has expanded significantly in recent decades, due to increased human demand for eggs and chicken meat. Therefore, it is critically important to mitigate challenges to the sustainability of modern poultry production, such as pollution, the depletion of finite natural resources and animal welfare issues. This study systematically mapped the scientific literature on farm-level sustainability in egg and chicken meat production. The concept of sustainability was considered holistically, covering its economic, environmental and social dimensions, each consisting of a broad range of different aspects that may contradict or reinforce each other. The literature published between January 2000 and March 2020 with a geographical focus on Europe, North America and Australia–New Zealand, were included. The literature search resulted in a total of 428 hits, but after the exclusion of articles that did not match the scope of the study, only 26 papers remained for the systematic mapping. Of these, only three papers covered all three dimensions of sustainability. Aspects of economic sustainability were addressed in 10 papers, aspects of environmental sustainability in 18 papers, and aspects of social sustainability in 23 papers. The findings in this study are an important foundation for the discussion and prioritisation of future actions to increase knowledge of farm-level sustainability in egg and chicken meat production.

Keywords: broiler; laying hen; environment; social; economic; animal welfare; ecology

1. Introduction

The domestic chicken (*Gallus gallus domesticus*), i.e., the broiler chicken and the laying hen [1], originates from the wild jungle fowl species *Gallus g. gallus* and *Gallus varius* [2]. Until industrialisation, breeding was mainly concerned with various body features such as colouring. However, human demands for productive performance, livability and health have influenced the domestication process over centuries [3]. The large genetic variation in, and adaptability of, the domestic chicken make it suitable for almost all climates on Earth, from the tropics to the temperate zones [1]. The global chicken population has increased greatly in recent decades, from 3.9 billion in 1961 to 22.8 billion in 2017 [4]. The broiler chicken population far exceeds the total number of other domestic birds in the world, including turkeys, geese and ducks, and also exceeds the largest global populations of wild bird species [4–6]. In 2017, total consumption of chicken meat (excluding indigenous breeds) was nearly 110 million tonnes, which was 12 times the amount in 1961. Similarly, global egg production increased by 450% between 1961 and 2017, to a total of 80 million tonnes [4].

The reason for this considerable growth in the domestic poultry population is the growing global human population, which is predicted to exceed 10 billion by 2055 [7], combined with a global increase in average per capita income. Poultry production provides humans with a source of animal protein, and also constitutes the main income for many farms and farming families around the world. Poultry production thereby contributes to some of the 17 global Sustainable Development Goals (SDG) set by the United Nation in 2016, including SDG1: *Zero hunger*, SDG3: *Good health and wellbeing* and SDG8: *Decent work and economic growth* [8]. However, poultry production may also jeopardise other SDGs, including SDG13: *Climate action* and SDG15: *Life on land*. The major challenges of modern poultry production include its contribution to emissions of greenhouse gases, loss of biodiversity and depletion of finite natural resources [9]. For a sustainable future poultry production, it is critical that these challenges are overcome. Efforts to develop a more sustainable future poultry production would benefit from a clear understanding of the current state-of-the-art, including how sustainability is considered and assessed, and on which future actions and research, prioritisations can be based. The literature to date considers various aspects of farm-level sustainability in egg and poultry meat production, but there have been no attempts to systematically map current knowledge.

The aim of this study was thus to perform a systematic mapping of the scientific literature on sustainability performance in egg and chicken meat production, including the environmental, economic and social dimensions of sustainability. We focused on studies conducted in Europe, North America, Australia and New Zealand, to enable emphasis on production systems based in similar economic contexts.

Sustainable agriculture has previously been defined as management and utilisation of the agricultural ecosystem in a way that maintains biological diversity, regeneration capacity, vitality, productivity and the ability to fulfil—today and in the future—significant ecological, economic and social functions at local, national and global levels, and does not harm the ecosystem [10]. The ecological aspects are central when considering sustainability in animal food production. However, the economic dimension of sustainability is also crucial, since agriculture is run by private firms for which revenues need to exceed costs, at least over the long term. There are also specific aspects of animal production, such as animal welfare, public health impacts and ethical considerations related to animal husbandry [11], which relate strongly to the social acceptance of production. This means that truly sustainable farm animal production requires these aspects to be taken into account. In fact, animal welfare has even been proposed as a fourth dimension of sustainable agriculture [11], and some authors have previously tried to incorporate animal welfare into life cycle analyses (LCA) of animal production [12]. The different dimensions of sustainable development (environmental, economic, social) may be in conflict, meaning that there are trade-offs between them, or they may function to reinforce each other.

In poultry production, environmental sustainability includes aspects ranging from the environmental impact of required feed production to the pollution caused by different production systems, and to the management of resulting harmful waste products. Nutrient pollution and emissions of, e.g., greenhouse gases, are considerable environmental challenges that require the identification of new solutions to reduce the environmental impact [13–15]. The intensive use of scarce natural resources, such as land exploitation and large monocultures of grain and soy, is another major environmental concern associated with the expansion of poultry production [16,17].

Economic sustainability in poultry production, often referred to in terms of, e.g., the economic output, productivity and efficiency of the production process, correlates strongly with the other dimensions of sustainability in poultry production. For example, the prevention of zoonotic diseases such as salmonellosis or avian influenza is not only of major importance for public health, but also has significant economic consequences [18]. Improving bird health and immunity is not only an animal welfare issue, but also affects the efficiency of the process by which production inputs are converted into production outputs, and thus the economic return of this process [19,20]. This also applies to environmental sustainability, as reduced production efficiency may lead to inefficient resource use,

and hence a higher impact per unit of, e.g., meat produced. However, the correlation is not solely positive, as, e.g., concerns about potentially large economic costs associated with improving animal welfare, have been voiced by industry stakeholders (e.g., [21]).

The social sustainability of poultry production is complex [22]. The use of antibiotics and resulting residues and resistant bacteria in soil, as well as in food products, poses a threat to human health [23,24]. The working environment may also constitute a risk to human health, since workers are exposed to noise, and an increased risk of respiratory diseases and injuries [25,26]. Moreover, the odours emitted by poultry houses may negatively affect neighbouring residents [27]. Another significant aspect is the importance of preserving animal biodiversity, as some poultry species have been lost through intensive farming [28,29]. On the other hand, poultry production contributes to food security and provides consumers with an affordable protein source.

In poultry production, it may be argued that genetic selection for increased productivity has been conducted with little attention to poultry welfare, and that the often very intensive processes applied in modern poultry production compromises animal welfare [28]. Another aspect to consider is the potentially negative economic consequences of legislation established with the intention to increase animal welfare, although such consequences may also be positive [21]. In other words, animal welfare may not only be perceived as important in itself, but also in terms of the other dimensions of sustainability.

By systematically mapping the existing literature on the farm-level sustainability of egg and chicken meat production in Europe, North America, Australia and New Zealand, in this study we sought to collate important knowledge on sustainability in egg and poultry meat production. This is useful as it provides a solid basis for highlighting research gaps and for prioritising future research to enhance sustainability.

2. Materials and Methods

2.1. Definition of Fundamental Concepts

2.1.1. Environmental Sustainability

Environmental sustainability is a natural, science-based dimension and, in principle, concerns the total impacts on ecosystems caused by human activities. The most commonly used tool for the quantification of environmental impacts is life cycle assessment (LCA), where flows of resources (energy, land, water etc.) into the production system and emissions from the system are quantified, and potential impacts described. The environmental impact caused by emissions, in all spatial scales, should also be included, as should the perspective of resource availability locally, regionally and globally. The scope of assessments of environmental sustainability should be the function of the production, and not the organisational boundaries, i.e., all flows to and from the production system need to be considered, regardless of economic ownership [30]. There are other methods besides LCA, most of which are similar regarding the basic principles but may use different approaches, in particular for the description of impacts. In this study, we included studies on the local impacts of poultry production and associated feed production, such as ammonia emissions from houses and manure storage, field emissions, and soil quality and biodiversity in crop production.

2.1.2. Economic Sustainability

From a theoretical perspective, economic sustainability can be considered in two ways. One way is to focus on the sustainable use of natural resources within a defined economic system, meaning that economic sustainability is achieved when the economic activity is not undertaken at the cost of natural resources. The economic concept of external effects is useful in understanding and fully capturing the costs associated with production. The other way is to focus on the growth of the economic system, which means that, in order to achieve economic sustainability, there must be a return on capital invested

in the firm. An interesting distinction can be made between weak and strong sustainability [31,32], which allows a distinction to be made between natural and economic capital. In particular, weak sustainability is about keeping the sum of those two types of capital. Strong sustainability is about keeping each type separately [32]. There is no clear consensus on how best to measure economic sustainability [33]. However, the sustainability accounting standards produced by the Global Reporting Initiatives [34] provide a perspective on which aspects to consider. In terms of economic indicators, this includes aspects such as costs, revenues, profit and investments.

2.1.3. Social Sustainability

Social sustainability is the least well-defined and most often overlooked dimension of sustainability [22]. Social sustainability can be defined as the ability of a community to develop processes and structures that not only meet the needs of its current members, but also support the ability of future generations to maintain a healthy community. In the present study, the concept of social sustainability applied included topics such as social equity, livelihood, health equity, community development, labour rights, community resilience and animal welfare.

2.2. Systematic Mapping Approach

A systematic mapping approach, also known as evidence gap mapping, was used in this study. Systematic mapping is a transparent, robust and repeatable method for identifying, collecting and sorting the relevant literature on a particular research topic [35]. It provides a structured overview of the research area [36], without aiming to answer a specific question [37]. Instead, the method serves to identify the state-of-the-art within a given research area, helps to identify knowledge gaps where future research is needed and provides useful information preceding, e.g., policy-making decisions [37]. Using a systematic mapping approach, no further synthesis of study results is performed. In contrast, a systematic review aims to answer a specific research question [37], through gathering relevant literature, further synthesising the results using an appropriate methodology, e.g., meta-analysis [36,37], and identifying knowledge gaps. In this study, the systematic mapping was complemented by a procedure where data were extracted from the studies included, in order to evaluate how the sustainability dimensions were described in these studies. This was done using a standard template, defined keywords and coding.

2.3. Search of Literature

A comprehensive search was performed using several information sources to obtain an unbiased sample of the published literature. The following online literature databases were searched to identify the relevant literature:

- Scopus;
- Web of Science Core Collection;
- CABI: Cab Abstracts.

The time span for the searches was set to papers published from 1 January 2000 to 20 March 2020, when the searches were conducted.

The search results were imported into EndNote X8™. A separate library was made for each search in the different databases. When the search was complete, all the libraries were incorporated into one new library and the number of references found was recorded. Using the automatic function in the EndNote X8™ software, any duplicates were removed. The library was then manually searched for references relevant to the topic. In addition to articles addressing the three dimensions of sustainability, a geographical limitation was also set, to only include studies conducted in Europe, North America, Australia and New Zealand, enabling a focus on studies on production systems in similar economic contexts. The exclusion due to geographical origin was done manually and was not set up in the searches. Papers both on poultry specifically as well as on farm animal production in general, explicitly

including poultry, were included. Furthermore, only full text papers in English were included. Initially, the titles of the papers were scanned and papers that clearly did not fall within the scope of this study were removed. Abstracts of the remaining papers were then read to identify relevant papers.

To find relevant papers dealing with poultry, the following search terms were used: ‘chicken* OR broiler* OR poultry OR egg* OR hen OR hens’. These were combined with search terms for the three dimensions of sustainability (see Table 1), which were defined through an iterative process among co-authors with different expertise. This ensured that possible search terms typically used in different research areas were included.

Table 1. Library search terms for environmental, economic and social sustainability.

Sustainability Dimensions	Search Terms ¹
Environment	(“environmental impact assessment” OR (environment* W/2 assessment) OR (environment* W/2 impact) OR (environment* W/2 protection) OR (climate W/1 change*) OR biodiversity OR ecosystem* OR pollution OR deforestation OR eutrophication OR (habitat W/2 destruction) OR (land W/2 degradation) OR (ozone W/2 depletion) OR “acid deposition” OR (odour W/2 emission) OR “air quality” OR “biochemical oxygen demand*” OR “chemical oxygen demand*” OR (nitrogen W/2 balance) OR (nitrogen W/2 cycle) OR (carbon W/2 cycle) OR eco-toxicity OR “carbon footprint” OR LCA OR “life cycle assessment”)
Economic	((agricultur* W/2 development) OR (agricultur* W/2 production) OR (farm* W/2 comparison*) OR (farm W/2 entrant*) OR (farm W/2 result*) OR (farm W/2 development) OR production OR diversification OR intensification OR “technical efficiency” OR “economic efficiency” OR “eco-efficiency” OR profit OR econom* OR return OR “economic viability” OR “economic performance”)
Social	((attitude* W/2 work) OR labour OR labor OR (quality W/2 life) OR “living condition*” OR “rural welfare” OR (work* W/2 condition*) OR “rural development” OR “social welfare” OR “social security” OR “social service*” OR “social equity” OR (health W/2 service*) OR “social status” OR (women W/2 status) OR “equal right*” OR equality OR (rural W/2 employment) OR livability OR “health equity” OR “labour rights” OR “labor rights” OR “social justice” OR “social capital” OR (community W/2 development) OR (community W/2 resilience))

¹ For the searches in Web of Science Core Collection and CABI: CAB Abstracts the Boolean operator NEAR was used and for the search in Scopus, the Boolean operator W was used. * The word was truncated for wider search.

3. Results

The literature search resulted in a total of 428 hits, of which 234 hits (55%) originated from CABI: Cab Abstracts, 120 hits (28%) originated from Scopus and 74 (17%) hits originated from Web of Science Core Collection. After removing duplicates and articles that did not match the scope of the study, i.e., non-peer reviewed reports, book chapters and review papers, a total of 26 papers remained (20 from Europe, five from North America and one from Australia), which were used in the systematic mapping process (see Appendix A).

The papers were assessed regarding the different dimensions of sustainability, and whether one, two or all three of these were covered in each article. During this mapping process, it became clear that aspects of environmental, economic or social sustainability were sometimes mentioned briefly, e.g., in the abstract or introduction, without actually being further explored in the paper. Therefore, “mentioned” was added as a third category, besides “covered” and “not covered”, for mapping the papers regarding their scope.

Of the 26 papers analysed (see Appendix A), only three covered all three sustainability dimensions, of which two also covered the animal welfare aspect. Six papers covered two dimensions, whereas 15 covered only one dimension of sustainability. Two papers did not explicitly cover any specific sustainability dimension, but merely mentioned two each (Figures 1 and 2).

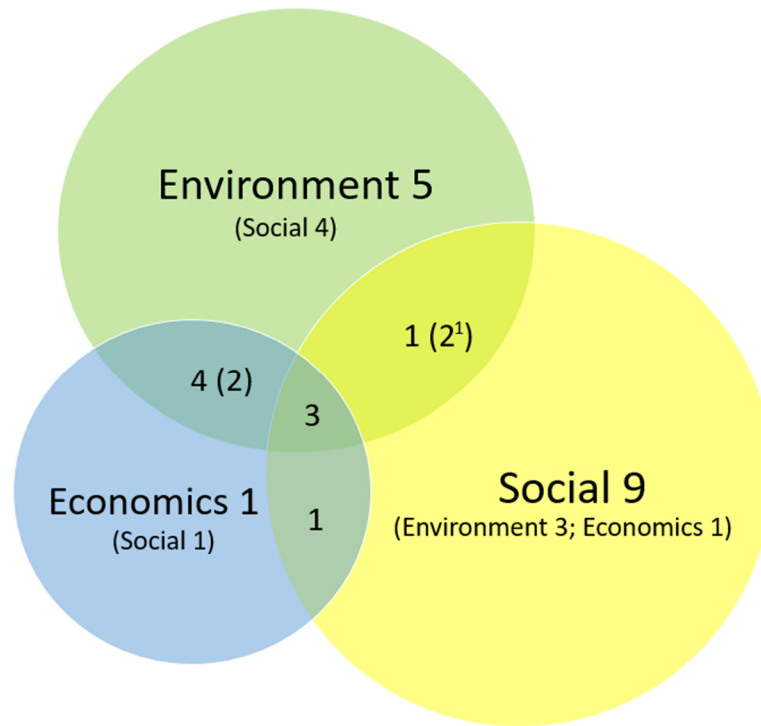


Figure 1. Number of the poultry articles covering and/or mentioning different aspects of sustainability (in brackets: number of articles merely mentioning different aspects); ¹ only mentioning environmental and social aspects, but not covering any of the dimensions.

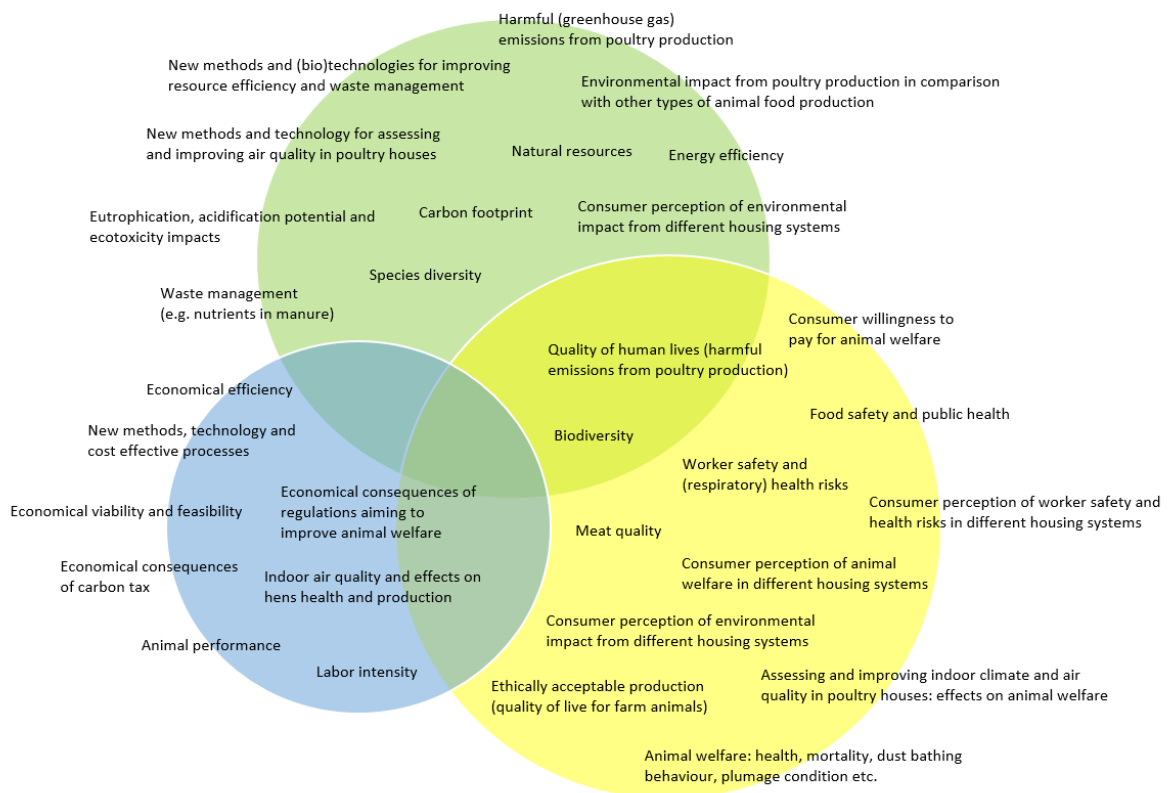


Figure 2. Keywords of the poultry articles covering and/or mentioning different aspects of sustainability; Economic—Blue; Environmental—Green; Social—Yellow.

Environmental sustainability was covered in 13 papers in total, economic sustainability in nine papers and social sustainability in 14 papers. Environmental sustainability was also mentioned in five papers, economic sustainability in one and social sustainability in nine. Animal welfare was covered in one and mentioned in two papers addressing economic sustainability, and mentioned in three papers on environmental sustainability. In the papers covering or mentioning social sustainability, animal welfare was covered in three and mentioned in two.

In the three papers covering all three dimensions, all applied a holistic view. One of these papers described a long-term study in which experimental farms were established to evaluate different possibilities of operating ecological agriculture whilst being, e.g., self-sustaining and economically viable as well as ethically acceptable, whilst stimulating biodiversity. Another of these papers applied an integrated systems approach to evaluate different already existing poultry production systems regarding environmental preservation, economic feasibility and human food needs and quality of life. More specifically, the potential impact of carbon pricing on the agricultural sector was assessed in one paper, including a reduction in carbon emissions, economic consequences and social aspects such as employment and household disposable income.

One aspect of environmental sustainability dealt with in the papers was the evaluation of new methods for waste management, e.g., biotechnologies for the bioconversion and recycling of organic waste products such as feathers, manure and litter (three papers). The efficient use of resources, e.g., land for poultry feed production, within different poultry production systems, and the ecological footprints of these, were also emphasised (five papers). Nitrogen and phosphorus pollution and emissions of carbon dioxide, ammonia, greenhouse gases, heavy metals and particles were also evaluated from an environmental perspective, considering different housing systems (six papers). While the objective of some papers was merely to describe a particular issue, others aimed at evaluating and providing new methods and technologies to deal with such challenges.

Economic sustainability, but no other dimensions, were explicitly covered in one paper only, in which the economic consequences of applying broiler welfare laws were assessed. In the remaining articles in which economic sustainability aspects were covered or mentioned, this was done in combination with at least one other dimension. Economic viability and efficiency, production costs (feed, material, labour, etc.), production performance (egg production, meat quality, mortality, etc.), revenue and net income were important aspects considered together with environmental and social aspects. For instance, papers evaluating new biotechnologies for waste management or novel methods enabling reductions in, e.g., greenhouse gas or particulate matter emission rates, did not do so solely from an environmental perspective, but also considering the potential positive or negative economic consequences (five papers).

The range of social sustainability aspects included in the papers was broad. One main aspect emphasised was working conditions and workers' health, respiratory health in particular, considering the poor air quality, bacterial contamination and high concentrations of particulate matter in poultry houses (four papers). In addition, public health in terms of food safety, e.g., persistent organic pollutants such as dioxin contamination of eggs, was covered (three papers). Consumer opinions about the environmental impact of different poultry production systems, as well as animal welfare and ethically acceptable poultry production (one paper), and consumer willingness to pay for the latter, was also explored (one paper). Animal welfare and bird health was also briefly mentioned (six papers), but never further specified, in association with, e.g., costs due to animal welfare legislation or new methods aimed at improving indoor air quality. One paper considered several social sustainability aspects in a social LCA, including the individual worker, local communities, value chain partners and society as a whole.

The majority of papers, on specific or somewhat broader research areas, e.g., indoor air quality, new technology for waste management and the environmental impact of different production systems, seem to allow for a direct application of results across country borders, assuming similar poultry production systems. Only a few papers, especially on consumer opinion, national legislation and

assessment of environmental impact on regional basis, were more country-specific, yet useful in a wider geographical context and not limited to national application.

Of the 26 articles included in this systematic mapping, eight were on broilers (of which one was not specifically on broilers, but on farm animal production in general) and ten were on laying hens (of which two were not specifically on hens, but on farm animal production in general). Eight of the papers did not specify poultry production further, and five of these were not specifically on poultry, but on farm animals in general.

4. Discussion

In this study, we used a systematic mapping method to obtain an overview of the current scientific literature (defined as original research papers published in peer-reviewed journals) on farm-level sustainability in egg and chicken meat production, including the social, environmental and economic dimensions of sustainability. The method further enabled the identification of the state-of-the-art within this research area, which provides a basis for discussing knowledge gaps. We found that only a limited number of papers covered all three sustainability dimensions within poultry production. This is surprising, considering i) that sustainability has been discussed in society for more than three decades, since the emergence of the Brundtland report in 1987 [38], and ii) that poultry production is an important part of the animal food production system in most countries. A larger proportion of the papers mapped covered one or two sustainability dimensions. Papers dealing with environmental or social sustainability were more common than papers considering economic sustainability, which was also more commonly covered or mentioned in association with one of the other two dimensions than on its own.

Using a systematic mapping approach means that search terms are carefully identified, to enable as great a coverage as possible of the published literature within the scope of the study. Due to the challenge of creating search strings that are specific and which give relevant results, yet at the same time are fully inclusive, no search can be flawless. In particular, this approach is associated with a risk of accidentally leaving out important search terms, which can bias the final results. Although our mapping contained search terms for all three dimensions of sustainability, there may be additional studies that relate to these dimensions, but which did not appear among the hits as they might not contain the words specifically used in our search strings. Thus, there may be other relevant papers that were not located in our searches. Another major challenge in this study was the very wide definitions of the three dimensions of sustainability used in the scientific literature. For example, the term environmental sustainability was used in different papers to describe studies ranging from full-scale LCA studies to energy use in a process line. Moreover, as our search strings included the word “egg”, several papers dealing with fish egg and eggplants had to be excluded after the initial searches. Nevertheless, the search strings used here can be considered quite comprehensive and the mapping probably covered a majority of studies dealing with farm-level sustainability in egg and chicken production.

Animal welfare was not included as a criterion in social sustainability when mapping the literature, but it was added during the reading process, as animal welfare is closely linked to the surrounding society’s view of animal production. However, the dimension of sustainable development to which animal welfare belongs is not evident, as it can be considered to be related to all three dimensions. Improved animal health and a reduced use of antibiotics is not only important for bird welfare, but for economic (reduced costs, increased productivity and product quality), social (public health) and environmental reasons (increased resource efficiency, reduced drug residues and resistant bacteria in soil) [24,39]. The concerns about animal welfare voiced by the public reflect the social acceptance of animal production, implying that animal welfare can also be considered to be closely related to social sustainability. Thus, in this study, animal welfare is regarded as an aspect of the social sustainability dimension. Alternatively, it should perhaps be treated as a dimension on its own. It should also be noted that other aspects of sustainable development may be interrelated in similar ways. However, our

systematic mapping revealed that the current literature (although, in several papers, more than one dimension of sustainability was briefly mentioned in, e.g., the introduction, without further exploration onwards) does not describe these interrelations or discuss possible trade-offs or synergies between different aspects. This is an important area for future research.

Systematic mapping involves search processes that are conducted using the same comprehensive method as a full review, but does not extend to a full critical data synthesis [35,40,41]. The systematic mapping method is useful in that vast and potentially diverse research areas, such as that considered in this paper, can be investigated (mapped) in a comprehensive way, whereas a systematic review enables substantial analysis of a more narrowly defined topic. In this study, we complemented the systematic mapping by extracting data from the studies to describe how the three sustainability dimensions were considered, using a standard template and defined keywords. This allowed us to create a more detailed overview of the literature compared with a regular systematic mapping approach.

In the mapping process, a number of aspects emerged, providing a basis to discuss research gaps and prioritise future actions and research. Although it was not within the scope of the current study to develop an exhaustive list of prioritised areas for future research, only to provide a basis for the reader to do so, we would like to highlight the following. First, it is obvious that few studies to date have considered all three dimensions of farm-level sustainability in egg and poultry production. This calls for (i) development at conceptual and modelling levels of more holistic sustainability assessments at farm level and (ii) the empirical application of such methods and approaches in egg and poultry production. Second, the mapping revealed that a broad set of aspects of sustainability dimensions have been considered in the literature. While acknowledging the contribution of previous research, future studies should take one step back and consider, at a conceptual level, how the different dimensions of sustainability in egg and poultry production are best measured at farm level, based on a conceptual understanding of sustainability. This would enable stronger theoretical underpinnings and better comparisons between studies. Finally, no previous study has attempted to assess how the dimensions and aspects of sustainability are interlinked in egg and poultry production, although this would provide a useful basis for better understanding how the individual aspects of sustainability can be enhanced. A way forward would be to perform an interdisciplinary study in order to develop a conceptual framework for a sustainability performance assessment of poultry production at farm and territorial level, where all three dimensions of sustainability are assessed, including potential synergies and conflicts between sustainability goals and targets.

5. Conclusions

We systematically mapped the scientific literature on farm-level sustainability in poultry meat and egg production, including all dimensions of sustainable development (environmental, economic, and social). We found that only a limited number of papers analysed all three sustainability dimensions within poultry production, but papers covering one or two of the three dimensions were more common. However, few of these actually describe interrelations or discuss possible trade-offs or synergies between the different aspects. Papers dealing with environmental or social sustainability were more frequent than papers analysing economic sustainability. These findings provide an important foundation for discussions and prioritisations of future actions to increase the knowledge of farm-level sustainability in egg and chicken meat production.

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Appendix A

The 26 papers that were analysed further, of which three papers were found to include all three sustainability dimensions; i.e., economic, environmental and social sustainability.

1. Arrebola, J.P.; Castano, A.; Esteban, M.; Bartolome, M.; Perez-Gomez, B.; Ramos, J.J. Differential contribution of animal and vegetable food items on persistent organic pollutant serum concentrations in Spanish adults. Data from BIOAMBIENT.ES project. *Sci. Total Environ.* **2018**, *634*, 235–242.
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