Journal of Cleaner Production 258 (2020) 120974

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Sustainability challenges and innovations in the Dutch egg sector

E.M. de Olde *, A. van der Linden, L.D. olde Bolhaar, I.J.M. de Boer

Animal Production Systems Group, Wageningen University & Research, P.O. Box 338, 6700, AH, Wageningen, the Netherlands

A R T I C L E I N F O

Article history:
Received 22 April 2019
Received in revised form
27 February 2020
Accepted 6 March 2020
Available online 7 March 2020

Handling editor: Yutao Wang

Keywords:
Laying hens
Environment
Obstacles
Farming
Trade-offs
Stakeholders

A B S T R A C T

While global demand for eggs is increasing, concerns are being raised about the environmental, economic and social impact of egg production. Efforts to address these sustainability concerns can, however, result in trade-offs. To enhance a transparent debate about future options and limitations in the egg sector, insight is needed in environmental, economic and social sustainability challenges as well as in potential trade-offs involved in addressing these challenges. Based on interviews with 24 stakeholders and supported by scientific literature, this paper presents an overview of current sustainability challenges and trade-offs in the Dutch egg sector. Moreover, the paper provides an overview of innovations suggested by stakeholders that can help to address the identified sustainability challenges, and describes current limitations for the implementation of these innovations. Innovations identified were related to animal health and welfare (n = 13), housing systems (n = 7), economy (n = 8), environment (n = 9), and organisation (n = 6). Stakeholders considered innovations to reduce particulate matter emissions as one with priority. In addition, controlling poultry red mite, approaches to translate costs for environmental investments to consumers, closing manure-feed cycles and improved collaboration in the chain were considered as important steps to address current sustainability challenges. Our results reveal the complex interactions between sustainability challenges in the egg sector and give insight in the different perspectives and considerations stakeholders have. Steps towards sustainable egg production therefore require multi-stakeholder dialogue to find consensus and jointly identify so-called small wins, i.e. meaningful and feasible steps that can contribute to a more sustainable food system.

1. Introduction

Poultry meat and eggs are an important source of animal protein globally. The production worldwide has increased sixfold since the 1960's and is expected to increase even further (FAO, 2016; Mottet and Tempio, 2017). Compared to other livestock products, eggs have a relatively low environmental impact per kg of protein, in terms of greenhouse gas emissions or land use (Poore and Nemecek, 2018). Poultry feed, however, includes a relatively high share of ingredients, such as grains, that are also edible for humans, and as such contributes to feed-food competition, and adds to the competition for natural resources such as land, water and phosphorus (Mottet et al., 2017; Steinfeld et al., 2006). Moreover, societal concerns related to poultry welfare and public health are increasingly raised (Boogaard et al., 2011; Bos et al., 2013; Mench and Rodenburg, 2018).

Over the past decade, changes in consumer demand in western Europe have resulted in an increase in demand for more extensive egg production systems, including free range and organic production (Mench and Rodenburg, 2018). This change, however, has resulted also in a higher emission of particulate matter (David et al., 2015) and a higher risk for avian influenza outbreaks (Bouwstra et al., 2017; Gonzales et al., 2013; Koch and Elbers, 2006). Trade-offs among sustainability challenges, such as the ones described above, need to be carefully considered when implementing innovations and new policies (Mottet and Tempio, 2017). To enhance a transparent debate about future options and limitations in the laying hens sector, we therefore need a clear understanding of the environmental, economic and social sustainability challenges, the multidimensional consequences of potential innovations, as well as the sector's capacity and limitations to develop and implement these innovations. As these challenges and innovations are to a large extent context specific, we selected the laying hen sector in the Netherlands as a case study for the following reasons. First, the Netherlands is the largest exporter of eggs within Europe, accounting for 40% of the value of exported eggs (EUROSTAT, 2017).

* Corresponding author.
E-mail address: evelien.deolde@wur.nl (E.M. de Olde).

https://doi.org/10.1016/j.jclepro.2020.120974
0959-6526/

Second, the Netherlands is densely populated, resulting in discussion about the environmental and social impact of livestock production (e.g. particulate matter, odour, greenhouse gases) and risk of zoonoses (Bos et al., 2013; Winkel et al., 2015). The way we keep our poultry is a topic of societal and political debates (Gremmen et al., 2018; Stevens et al., 2018). To define future directions for sustainable egg production, we need a clear understanding of how and why stakeholders (dis)agree on sustainability challenges, solution pathways and their potential trade-offs (Swanson et al., 2011; van Asselt et al., 2017). So far, a systematic overview of the sectors' sustainability challenges and trade-offs, and innovations and obstacles for their implementation is lacking. Our aim, therefore, is to provide such an overview based on interviews with stakeholders in the Dutch egg sector which can contribute to navigating the egg sector towards more sustainable modes of production.

2. Methods

2.1. Interviews and survey

To gain insight into the characteristics of the Dutch egg sector, a multi-stakeholder approach was applied to study the sectors' sustainability challenges, trade-offs, innovations and obstacles. Semi-structured interviews were carried out with 24 stakeholders (Table 1). A set of interview questions was prepared (Supplement 1) and where relevant follow-up questions were asked during the interview. Stakeholders were selected based on their role in the Dutch egg sector, and their representation across stakeholder types (see Table 1), across the food chain and across spatial scales and associated policy levels. Moreover, in selecting researchers we focused on including researchers working on environmental, economic and social issues in the sector. The list of interviewees included four farmers who were selected based on a diverse range of innovations they apply on their farm. For the interviews with policy makers at the local and regional level, the two municipalities (Barneveld and Ede) and province with the highest number of laying hen farms in the Netherlands (Gelderland) were selected.

Interviews were carried out in the period November 2017 to January 2018 and lasted on average 1 h (with a range of 45–120 min). The interviews were recorded and fully transcribed. To analyse the qualitative content, the transcripts were systematically coded and analysed using Atlas. ti (version 7.0), a software application for qualitative data analysis (Friese, 2013; Muhr, 1991). The content analysis was based on an inductive approach starting from the raw data without a fixed coding framework in mind (Finfgeld-Connett, 2014). The transcripts were coded to identify main issues brought forward by the interviewees. This included specific sustainability challenges, sector related concerns, innovations and obstacles. A second, more in-depth, round of coding was carried out to identify more specific issues but also to keep track of the framing of issues, in other words, how an issue was discussed and related to other aspects. The coded sections were then analysed and clustered to present an overview of sustainability challenges, trade-offs, a list of innovations (in five themes), and obstacles for the implementation of innovations.

Table 1
Number of interviews per type of stakeholder.

Type of stakeholder	N
Farmers and farmer organisations	5
Poultry chain organisations	3
Local, regional and national governments	4
Agrifood industry (suppliers and egg processors)	5
Research, education and consultancy	6
Non-governmental organisations	1
Total	24

To gain insight into which innovations were considered to have priority, a follow-up survey was carried out in September 2018. Using an online survey, the 24 stakeholders were asked to identify which innovation, within each of the five themes (animal health & welfare, housing systems, economy, environment and organisation), had key priority. Priorities selected by the group of four innovative farmers may deviate from the priorities selected by a more representative group of farmers. To gain insight into the perspectives of a more representative group of farmers, we involved 17 farmers with laying hens working in the province of Gelderland and participating in the ERA-Net AnimalFuture project. These farmers were asked also which innovation they would prioritize for their farm, and for the egg sector in general, and which obstacles they would foresee for the implementation of innovations.

2.2. Egg production in the Netherlands

While being EU's largest exporter, the Dutch egg sector is relatively small in the number of farms. In 2017, 993 laying hen farms and 58 farms with parent stock were present in the Netherlands. In total, these farms housed approximately 46 million laying hens and 1.5 million parent stock. Compared to the year 2000, the number of laying hens has increased by 5%, whereas the number of farms declined rapidly with 57% (CBS, 2018b). As a result of this upscaling, the average number of animals per farm more than doubled over this time period and is currently about 46,800 hens per farm. Farm size varies, however, strongly between regions and housing systems. In the Netherlands, 14% of the hens are kept in cages (enriched or colony), 60% in barn systems, 19% in free range and 7% in organic systems (Agrimatie, 2018). These percentages are different for the number of farms per system, as organic and free range farms are generally smaller. Of the 993 laying hen farms, 225 were organic with an average of 14,300 hens per farm (CBS, 2018a). The majority of Dutch laying hen farms are located in the provinces Gelderland (32%), Noord-Brabant (15%) and Limburg (14%), accounting for 26%, 18% and 27% of the animals, respectively (CBS, 2017). Farms in the province of Gelderland are, on average, smaller and hens are kept in more extensive systems compared to the province of Limburg.

The Netherlands produces approximately 10 billion eggs and imports an additional 3 billion eggs per year (Sorgdrager, 2018). About 60–65% of the Dutch eggs are exported, mainly to Germany (75%) and Belgium (11%). The economic value of this export was 470 million euro in 2016. Besides the trade in consumption eggs (in shell), between 30 and 35% of the Dutch eggs are processed into egg products, such as bakery products, pasta, sauces, or ice cream (van Horne et al., 2017).

The egg production chain in the Netherlands consists of many individual entities. After leaving the farm with parent stock, eggs are hatched in one of the eight hatcheries in the country (Sorgdrager, 2018). The chicks are then reared on a rearing farm (n = 150) before they start their production on a laying hen farm. On the majority of farms, eggs are collected and traded by one of the approximately 120 packing centres of which the 5 largest have a market share of 80% (Sorgdrager, 2018; van Horne et al., 2017). Eggs are mainly sold to consumers by supermarkets (90%) (Sorgdrager, 2018).

3. Results and discussion

3.1. Sustainability challenges

Stakeholders were asked what they perceived as specific sustainability challenges for the laying hen sector in the future. Stakeholders mentioned a wide variety of challenges across sustainability dimensions. The challenges were clustered in sustainability issues (e.g. emissions or animal health) and divided into the three dimensions of sustainability (i.e. environmental, economic and social) (Table 2). Addressing the identified challenges often involves trade-offs. In the sections below and in Table 2 we describe all the identified challenges and trade-offs among them in more detail. The challenges and issues brought forward by stakeholders are discussed in relation to recent scientific literature. Quotes from the interviews are used to show how current sustainability trade-offs result in dilemmas in egg production.

3.1.1. Environmental sustainability

Stakeholders mentioned specific sustainability challenges related to the following environmental issues: emissions, transport, carbon footprint, (environmental impacts associated with) livestock feed, manure, and resource use (Table 2).

The impact of emissions of particulate matter, odour and ammonia on public health gained attention in the Netherlands after several recent publications studying the link between air quality and public health (e.g. (IJzermans et al., 2018; van de Weerdt and Zuurbier, 2017)). In addition to the impact on public health, it is a concern for the health and welfare of farm workers and animals (Mench and Rodenburg, 2018). Particulate matter emissions have increased as a result from the transition from battery cage systems to alternative housing systems (barn, free range and organic) which are characterised by larger litter areas and higher bird activity levels (David et al., 2015). As a result, municipalities with high numbers of farms are confronted with high concentrations of particulate matter, especially PM10 (van de Weerdt and Zuurbier, 2017). In addition, transport to and from farms contributes to particulate matter emissions as well as to the emission of CO_2. To address particulate matter emissions, the Dutch Poultry Expertise Centre has initiated on-farm pilots to test a range of particulate matter emission reducing techniques (PEV, 2020). Several stakeholders, however, raised concerns regarding the economic implications of introducing emission reducing techniques on-farm as well as the possible trade-off with energy use.

Although the carbon footprint of eggs is relatively low compared to other animal sourced products (De Vries and De Boer, 2010; Poore and Nemecek, 2018), stakeholders expressed that systems with higher levels of animal welfare generally perform worse in terms of their carbon footprint as a result of a higher feed conversion ratio (Dekker et al., 2011). Nevertheless, with regard to sustainability issues, consumer interest has predominantly been focused on animal welfare:

> “We notice in the sales of our products, whether these are eggs, table eggs or egg products, that animal welfare is valued most. So, if keeping hens with an outdoor access reduces feed conversion, than this loss in feed conversion is subordinate to welfare” (Egg processor).

The efficient use of feed, in relation to a growing demand for animal source food, was a prominent issue in the interviewees with stakeholders. As feed represents the main economic cost in egg production and feed conversion is important in terms of carbon footprint and land use, feed conversion has received a lot of focus (Dekker et al., 2011). Nevertheless, reducing the feed conversion ratio can result in feeding higher quality feed with a higher risk on competition with human food. This trade-off is not considered in the carbon footprint approach (De Boer and Van Ittersum, 2018). One of the stakeholders brought forward a dilemma related to using resources efficiently:

> “Are you going to breed chickens that require less feed, so more efficient with good feed, or should I breed my chickens with a higher feed intake to deal with all kinds of by-products. So, what is than feed conversion?” (Poultry breeder).

Using by-products (e.g. crop residues, co-products from food processing and losses and waste from the food system), means feeding animals with biomass that humans cannot or do not want to consume. This strategy is considered as a way forward to use land wisely, prevent feed-food competition and use arable land primarily for food production (Van Zanten et al., 2018). In line with this approach, the Dutch Minister of Agriculture, Nature and Food Quality launched in 2018 a vision aimed at transitioning towards a more circular agriculture (Schouten, 2018). As illustrated by the

Table 2
Overview of sustainability issues, their specific challenges and trade-offs involved, and innovations related to the issues (codes refer to innovations listed in Table 3).

Dimension	Issue	Specific challenges	Trade-offs (involved in addressing the issue)	Related innovations
Environment	Emissions	Particulate matter, odour, ammonia, public health, air quality, farmer health & welfare, animal health & welfare	Animal welfare, energy use, economic cost	H1; H3; H5; Env5; Ec4
	Transport	Particulate matter, Carbon dioxide		A6
	Carbon footprint	Carbon footprint, feed conversion ratio	Animal welfare, feed-food competition	Ec6
	Feed	Origin (import vs regional), content (non-GMO, soy), by-products, insects, feed-food competition	Economic cost, carbon footprint, phosphate efficiency, feed conversion ratio	A10; Env 8; Env 9; Ec6
	Manure	Nutrient and manure surplus	Resource use	Env2; Env 5-7
	Resource use	Land use, energy use, nutrients	Animal welfare	H4; Env2; Env5-7
Economic	Farm income	Farm income, chain integration, scale of capital flows, financial risk	Landscape quality	Ec1-8; Env1; O2
Social	Animal welfare	Housing systems, debeaking, killing one-day-old male chicks, societal demand, outdoor access	Feather pecking, feed conversion ratio, animal health, emissions, public health	A1-3; A6
	Animal health	Outdoor access, Avian Influenza, antibiotics	Animal welfare	A4-13
	Public health	Avian Influenza, emissions	Animal welfare, economic cost	H1; H3; H5; O6
	Working conditions	Emissions	Economic cost	H1
	Farm succession	Successors		
	Food safety	Dioxin, salmonella, fipronil		O6
	Human consumption of animal protein	Human consumption of animal protein, resource use		Env1-3
	Relation to society	Societal support, recognition, connection to consumers, activism		H7; Ec2; O1

Table 3
Innovations for the Dutch egg sector identified through the interviews.

Theme		Innovations
Animal health & welfare (A)	1	Roosters: in-ovo selection
	2	Roosters: market roosters
	3	Multipurpose breeds for meat and egg production
	4	Avian Influenza vaccine
	5	Poultry red mite management (diverse techniques e.g. Q perch, use of herbs, better light in the barn and weekly cleaning)
	6	Transport reduction through farm integration
	7	Breeding and genetics (improvement in longevity, egg quality, feed efficiency, digestion of by-products, reduce aggression)
	8	Gene editing (e.g. for Avian Influenza)
	9	Sensors for the detection of diseases and monitor behaviour, use of data to improve management
	10	Feeding insects to improve health and welfare
	11	Germinated grains as feed
	12	Systematic veterinary support
	13	Robustness (focus on disease resistance, less on production)
Housing systems (H)	1	Emission reducing techniques (e.g. reduce particulate matter, ammonia and odour such as manure drying tunnels, litter removal systems, heat exchanger, air ionisation, filters etc.)
	2	Covered outdoor area or inner garden as a possible solution for avian influenza risks
	3	Litter and dust bathing solutions (solutions to reduce dust bathing in own manure)
	4	Energy production (integrate renewable energy in the housing e.g. solar panels, geothermal energy)
	5	Permits (from mean-to-goal oriented permits – use sensors to monitor emissions instead of using a fixed list of emission factors per system)
	6	Mobile housing systems/chicken sheds
	7	New housing systems or farm designs for integral sustainable farms, visibility and transparency of the farms
Economy (Ec)	1	Create farm or egg concepts with added value (examples include Kipster, Rondeel, OerEi (fed on insects), Gezondheidsei (Healthy egg) as well as selling roosters and soup chickens, and the use of certification schemes)
	2	Local and direct sales as revenue model and as direct link to the consumer
	3	Change European trade agreements to recognize a housing system with covered outdoor run
	4	Demand oriented production (focus production on demand instead of supply, make agreements with retail)
	5	Translate the costs of environmental investments to the consumer (e.g. emission reducing techniques) using an investment fund or concept with added value
	6	Carbon credits (include the CO_2 footprint in the price of products)
	7	Shorten the depreciation period of a farm to encourage innovation and renewal
	8	Quality control of the eggs on farm (sorting and selecting eggs on farm to gain insight in quality and improve transparency in the chain)
Environment (Env)	1	Consumption change (better use and revenue for all chicken parts)
	2	Consumption reduction (reducing livestock production and consumption)
	3	Meat and protein alternatives like in vitro meat
	4	Lowering the stocking density to reduce particulate matter emission
	5	Drying poultry manure - manure pellets to sell
	6	Manure incineration for energy production
	7	Closed cycles (closing feed-manure cycles on a smaller scale, feed from the region)
	8	Feeding insects (produced on manure or leftovers)
	9	Feeding leftovers and by-products
Organisation (O)	1	Consumer information (improve information to consumers e.g. using QR codes, invest in the relation to society, improve transparency, acknowledge the farmer as food producer)
	2	Collaboration in the chain to improve the revenue model (producers organisation, collective buying, new collaborations)
	3	Improvements in representation of the chain
	4	Chain integration to improve optimisation and information exchange
	5	Calamity fund
	6	Block chain technology (passports across the chain)

quote, it requires a new approach and raises new questions related to availability, quality and safety of by-products. Several stakeholders discussed the role insects could play in processing by-products and providing livestock feed.

Also the origin (e.g. South America or more local) and composition (i.e. soy, no Genetically Modified Organisms (GMO) ingredients) of the feed were mentioned as sustainability challenges. The increasing demand for eggs produced with non-GMO feed (i.e. Verband Lebensmittel ohne Gentechnik (VLOG) certified), results in an increased demand for non-GMO feed ingredients and/or alternatives to GM soy and maize (Castellari et al., 2018). This can result in higher feed costs for farmers and negatively affect the phosphate efficiency and carbon footprint of the feed.

Not only the efficient use of feed was mentioned as a sustainability issue for the future, also resource use in general, including land, energy and nutrients, was brought up. Opportunities for energy production through windmills and solar energy on-farm were suggested as innovations (Table 3). A more contested source of energy production is the incineration of poultry manure for energy production. Approximately one third of Dutch poultry manure is incinerated in a biomass installation in Moerdijk (Billen et al., 2015). While some stakeholders considered this as a good solution to address the surplus of manure in the Netherlands, others believe this is a waste of valuable resources. A more circular approach, by better connecting feed and manure cycles on a more regional level was suggested by several stakeholders to address challenges related to nutrient and manure surpluses (see section 3.2).

3.1.2. Economic sustainability

With regard to economic sustainability, farm income was mentioned as a key issue (Table 2). Several stakeholders expressed limited farm income as one of the main weaknesses of the sector. Due to limited integration of entities in the egg production chain, each entity is striving for its own gain.

> "The business model of the packing centre is currently that the poultry farmer doesn't earn anything, and the business model of

the poultry farmer is actually that the packing centre doesn't earn anything" (Poultry farmer).

Solutions to improve farm income or income elsewhere in the chain are considered to be limited as the sector operates in a free market system and responds to changes in supply and demand.

"[poultry farmers in] the organic sector currently have a good income. But this acts as an enormous pull factor. We already know of dozens of projects that are being developed to keep organic hens. As a result, we will have a surplus of organic eggs in a while. And a disaster with unforeseeable consequences is imminent. Because we have a free market, we cannot prohibit anyone to keep organic hens" (Egg processor).

The continuous upscaling of farms was also mentioned as a sustainability challenge. Upscaling of farms has implications for the magnitude of the capital flows and associated financial risks. Moreover, it can have an impact on the visual appearance of the farm in the landscape and its acceptation by the local community, which is more a social sustainability issue.

3.1.3. Social sustainability

In terms of social sustainability, issues mentioned included: animal welfare, animal health, public health, working conditions, farm succession, food safety, human consumption of animal protein, and the sector's relation to society (Table 2).

Animal welfare is an important issue in the sector. Over the past decades, the sector has been confronted with changes in legislation and consumer demand related to animal welfare. After the ban on battery cage systems, a transition towards more animal friendly systems has been made. In addition to current animal welfare standards in the four main housing systems (i.e. enriched cage, barn, free range and organic), additional animal welfare requirements (e.g. stocking density, covered outdoor access, light intensity, enrichment material) have been formulated as part of the Dutch Better Life concept. In 2018, in response to German consumer demand for eggs of non-debeaked hens, and Dutch regulations (2019), farmers had to shift to non-debeaked hens which posed challenges with regard to addressing pecking behaviour and aggression, and selective eating behaviour. A controversial issue mentioned by stakeholders is the killing of one-day-old male chicks (Gremmen et al., 2018). An alternative would be to select males in the egg before birth (in-ovo selection). Although this field is developing rapidly, this is not yet a feasible alternative for commercial scale operations. Keeping the roosters for meat production presents another alternative, and is done on small scale, yet, the feed conversion ratio of this production is high, making it a contested issue in terms of resource use efficiency.

"But fattening a rooster requires a lot of feed, a lot of land, a lot of water, a lot of energy. That clearing your conscience, in fact, goes at the expense of food supply of the others. That is just unfair" (Poultry farmer).

In the Netherlands hens are increasingly kept in systems with outdoor access (26% in 2018, compared to 15% in 2008), in response to an increasing market demand for eggs produced in free range or organic systems. Outside access and fresh air are considered as most important aspects for hen welfare by consumers of free range eggs (Pettersson et al., 2016). Outdoor access poses, however, challenges for animal health.

"Outdoor access is nice, is beautiful, however, there are risks" (Poultry farmer).

Especially the risk for the outbreak of avian influenza was often mentioned by stakeholders. The Netherlands has been confronted with regular outbreaks of Avian Influenza, often Low Pathogenic Avian Influenza (LPAI). Farms with outdoor access are considered to have a higher risk for LPAI compared to farms without an outdoor run (Bouwstra et al., 2017; Gonzales et al., 2013). Not only for animal health, also for public health, Avian Influenza can pose a risk. Especially in regions with a high livestock and human density, such as the Netherlands, the risk of transmission to other farms and humans is present (Jonges et al., 2015; Koopmans et al., 2004). For that reason, many stakeholders suggested innovations to address this issue, either through vaccination or using a covered outdoor area (Table 3). Other animal health aspects mentioned included improving the life span of laying hens and reducing antibiotic use. Although antibiotic use was mentioned by some stakeholders, others emphasized that it's not an issue as the use of antibiotics is relatively low in laying hens (0.9 daily doses per animal year) (Heederik, 2018).

The emission of particulate matter can be considered both as an environmental and a social sustainability issue (i.e. public health). Recent studies investigating the impact of livestock farms on the health of local residents (Freidl et al., 2017; IJzermans et al., 2018; Kalkowska et al., 2018; Poulsen et al., 2018; Smit et al., 2017; van Dijk et al., 2017) suggested an association between pneumonia and proximity of poultry farms (Kalkowska et al., 2018; Poulsen et al., 2018; Smit et al., 2017), but further research is required to establish such an association. The impact of particulate matter on health and working conditions of farmers and farm workers was mentioned as a social sustainability issue.

"Last week I visited one [farmer] who is 65 years old, his farm will be taken over by his son, who is 25, he said: 'you don't think I expect of him to walk in this dust mess for 40 years'" (Poultry consultant).

As illustrated by the quote, this can affect farm succession, another well-known sustainability issue. Approximately 46% of Dutch poultry farmers of 55 years or older have a successor. This varies, however, between regions and farm size (CBS, 2016).

Food safety, including aspects such as dioxin and salmonella, is considered by stakeholders as a precondition that will remain important in egg production. Although one stakeholder mentioned that housing systems without outdoor access have a higher food safety level, hence a trade-off between outdoor access and food safety, no consistent differences have been found in literature (e.g. risk on *Salmonella enteritidis* infections) (Holt et al., 2011; Mench and Rodenburg, 2018). Many factors can play a role in the health status and food safety of hens including hen age, flock size, season, breed, disease status, rodent and insect load (Holt et al., 2011). Nevertheless, chemical contamination is a risk for hens in all systems (Mench and Rodenburg, 2018). At the start of this study, in 2017, fipronil was detected in Dutch and Belgian eggs. A Dutch company had illegally used fipronil to combat poultry red mite on poultry farms. As the concentrations of fipronil found in eggs could possibly be harmful for children when consumed daily, the Netherlands Food and Consumer Safety Authority blocked nearly 200 farms which were no longer allowed to transport eggs, chickens and manure off their farm. The fipronil affair had an high emotional and financial impact on the egg sector (Sorgdrager, 2018). The importance of addressing poultry red mite can also be recognized in the innovations (Table 3).

A few stakeholders mentioned human consumption of animal protein as a sustainability issue for the future. As mentioned above, making efficient use of resources is important to address challenges related to scarcity of resources and a growing and increasingly affluent world population. This raises questions on whether we should consume animal protein in the future, if so, how much, and what the alternatives are (Parodi et al., 2018; Van Zanten et al., 2018).

> “And I believe that, if we want to contribute to feeding the world, we simply need to reduce animal products. And this is a very difficult message when you work with animal products and when your entire … or yes, a large part of your network is working in animal production” (Poultry farmer and co-founder of Kipster).

A final social issue that was often raised by stakeholders was the importance of having societal support and recognition for the sector. This relates not only to society as consumers but also to the neighbouring community. Listening to societal wishes (e.g. through market demand), involving society in the development of your concept, understanding underlying values of stakeholders, and establishing connections to society (e.g. through education, packaging) to inform consumers about farming practices was mentioned as important, also in light of recent social media campaigns and undercover videos published by NGO’s and activists (Busch, G. and Spiller, A., 2018a, b; Stevens et al., 2018; van Asselt et al., 2017). Pressure from activists and consumers are considered to play an important role in the enforcement of animal welfare standards by retailers (Grandin, 2014; Scrinis et al., 2017).

3.2. Innovations

Innovations can contribute to addressing many of the sustainability challenges mentioned. In total, the interviewed stakeholders mentioned 177 innovations. After deduplication and restructuring, these innovations could be organised in five main themes: animal health & welfare, housing systems, economy, environment and organisation (Table 3). As the number of times a certain innovation was mentioned may not represent the priority a certain innovation has to improve a theme, a follow-up questionnaire was sent around to the stakeholders as well as to a group of 17 farmers participating in the AnimalFuture project. Both groups were asked to select one innovation within each theme that they would prioritize. In total, out of the 24, 18 responses of stakeholders were recorded and can be found in Fig. 1. In addition, the responses of 17 farmers on which innovation has priority for their farm and for the sector are given in this figure.

Within the theme animal health and welfare, techniques that can contribute to the management and control of poultry red mite were considered to have key priority by one third of the stakeholders. In addition, they considered developing an in-ovo selection method to address the killing of one-day old male chicks, and the use of sensors to detect diseases and monitor behaviour as important innovations. Similarly, nearly half of the farmers considered innovations related to poultry red mite as a priority for their farm. For the sector in general, however, farmers felt it was important to develop solutions for in-ovo selection of roosters. Also the development of an Avian Influenza vaccine was considered as a key priority by several farmers, both for their own farm and for the sector in general (Fig. 1).

For housing systems, innovations that can reduce emissions of particulate matter, ammonia and odour using different types of techniques were prioritized by the stakeholders. This could involve new housing systems or integral farm designs to address concerns regarding public health. Moreover, the option to cover the outdoor area or create an inner garden was considered as a potential solution to address the risks for avian influenza outbreaks. Farmers agreed upon the importance of innovations to reduce emissions. The vast majority of farmers also considered emission reduction as a key priority for the sector. For their own farm, however, one third of the farmers prioritized innovations that can also provide economic benefits, such as solar energy production (Fig. 1).

Opinions on what has priority with regard to economic innovations varied between stakeholders. Translating the costs of environmental investments (e.g. investments made in reducing emissions) to consumers using an investment fund or concept with added value was a key priority according to five stakeholders (Fig. 1). Creating new farming or egg concepts focused on, for example, health, circularity or animal welfare to create a price premium for farmers, was also considered as a priority innovation. Also amongst farmers, priorities related to economic innovations varied, especially with respect to innovations at sector level. For their own farm, nearly half of the farmers considered local and direct sales as revenue model and as direct link to the consumer as a priority. Also the development of a farm or egg concept was seen as a priority by several farmers. For the sector, however, two other innovations were considered important: development towards demand oriented production (focused on demand instead of supply) and translating the costs of environmental investment to the consumer (e.g. of investments made to reduce emissions). Especially the latter, would require a sector wide approach which explains why it was prioritized for the sector level, and not for individual farms.

More aligned were stakeholders with regard to what has priority in terms of environmental innovations. Fifty percent of the stakeholders gave priority to innovations that could add to circularity by closing feed-manure cycles on a smaller scale. Feeding insects produced on manure or leftovers could fit into a more circular approach and was considered as a priority by six stakeholders. Farmers’ priorities related to environmental innovations differed from those identified by the other stakeholders, but also among farmers. Solutions to address manure surplus (i.e. drying poultry manure or manure incineration) were considered as a priority for their farm by in total 41% of the farmers. While some of stakeholders had argued against this (section 3.1). Nearly 30% of the farmers prioritized innovations related to feeding (i.e. insects or by-products) for their farm. For the sector, 30% of the farmers felt that consumption change (making better use and revenue of all chicken parts) has priority, and another 30% focused on manure incineration for energy production (Fig. 1).

Finally, organisational innovations that could contribute to collaboration in the chain to improve the revenue model for farmers were according to 50% of the stakeholders a priority. Also 41% of the farmers considered this a priority for their farm. Also innovations related to consumer information were considered a priority, by some of the stakeholders and by farmers (both for their farm and for the sector).

3.3. Obstacles for the implementation of innovations

When stakeholders were asked which obstacles are currently limiting the development and implementation of innovations, the majority mentioned laws and regulations as a barrier. EU regulations, for example, currently prohibit the use of insects in poultry feed. Laws and regulations are often perceived as restrictive for innovation (De Olde et al., 2016). In particular, municipal permits related to ammonia emissions were mentioned. These are currently based on fixed emission factors determined for specific housing systems and livestock species. Several stakeholders suggested a

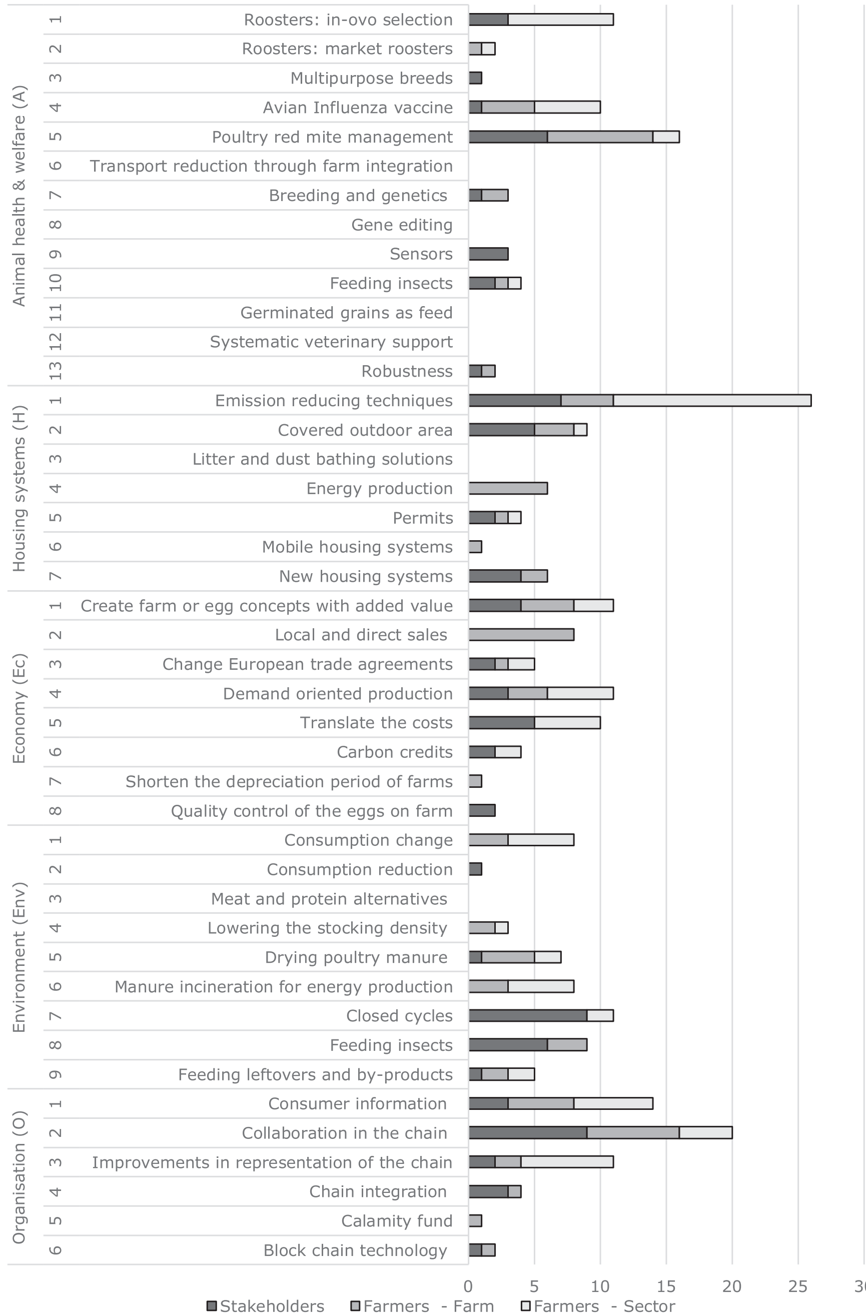

Fig. 1. Innovations for the Dutch egg sector and their priority according to stakeholders (n = 18) and farmers (n = 17; specified for their farm and for the sector in general). Stakeholders and farmers selected one innovation per theme. Bars indicate the absolute number of stakeholders and farmers selecting an innovation.

transition towards a goal-oriented approach (i.e. lowering ammonia emissions) based on on-farm monitoring of the emissions using sensors instead of a means oriented approach based on predetermined emissions factors of the housing systems and technology applied. This could give more transparency to farmers and local communities in the real-time emissions of farms and could provide farmers with more flexibility to address these environmental challenges. Another restriction mentioned related to this topic was that the process of getting a housing system or technology approved by the Dutch ministry takes relatively long and requires sharing of information, which could be a competitive disadvantage.

A second main obstacle is financial resources. Stakeholders indicated that for individual farmers, pressure on farm income is limiting the opportunities to invest in innovations. Moreover, the need for a form of risk coverage was expressed as innovations are often associated to higher costs and labour investments it involves a higher risk to invest in (De Olde et al., 2016; Min et al., 2006). As a sector, the abolishment of the national product board for poultry and eggs in 2015, which used to collect collective funding for research and innovation, has limited collective investments in research and innovation. A new form of raising collective funding, however, has been developed and was approved in April 2018 (Ministerie van Landbouw, 2018).

Other barriers mentioned by stakeholders related to politics (i.e. changes in politics and the focus on free market), bureaucracy (long and complex subsidy procedures), requirements from certification organisations and limited collaboration between institutes. Finally, the presence of certain convictions in farming, society and politics on what is considered as good or bad, sustainable or unsustainable, can present a barrier. Examples of convictions mentioned include the focus on increasing productivity, perceptions on gene editing and the ban on phytase feed enzymes in organic agriculture.

The majority of the farmers (13 out of 17) that were interviewed mentioned limited financial resources as the main obstacle for the implementation of innovations on their farm. Also restrictions due to a limited farm size and availability of land, limited time, regulations or lack of farm succession were mentioned as obstacles or limitations for the implementation of innovations.

4. General discussion

The innovations identified in this study are in many cases directly linked to the sustainability challenges mentioned by stakeholders such as particulate matter emission, avian influenza and the killing of one-day-old male chicks. Moreover, the prioritized innovations resonate recent developments in the Dutch sector including the 2017 fipronil affair (i.e. poultry red mite management) (van der Merwe et al., 2019), outbreak of highly pathogenic Avian Influenza on poultry farms in 2017/2018 (Beerens et al. 2017), publications in 2016 and 2017 on the public health impact of livestock production (i.e. emission reducing techniques) (IJzermans et al., 2018), and the opening of Kipster, a farm which integrates innovations related to marketing, particulate matter emission, feeding by-products and rearing of roosters (Kipster, 2019). As such, the priorities identified by farmers and stakeholders are context-dependent. Despite this context-dependency, many sustainability challenges identified in this study have also been recognized in other studies looking at the sustainability in egg production (Mench and Rodenburg, 2018; Mollenhorst and de Boer, 2004; Soisontes, 2017; Vaarst et al., 2015). In our study, however, we have also identified sustainability issues relating to the broader societal and ethical context that so far have received very little attention in sustainability studies in egg production.

Soisontes (2017) presented an overview of sustainability concerns in the poultry industry in Germany and Thailand. As Germany is the largest consumer of Dutch eggs, similarities between sustainability concerns can be expected. The top 10 of main concerns in Germany included several animal welfare issues including the killing of male layer chicks (no. 1), de-beaking (no. 4), stocking density (no. 8) and housing system (no. 9). Especially the importance of killing of male layer chicks can be recognized also in the Dutch priorities for innovations. Also the role of food retailers (no. 3), resource use (no. 6) and societal acceptance (no. 7) were important issues that were also brought forward in this study. The use of antibiotics was both in Germany and Thailand a top-10 concern which could be explained by the focus of the paper on both meat and egg production. The use of antibiotics is higher in meat production compared to egg production (the focus of our study) (Heederik, 2018). Number one concern in Thailand was the outbreak of Avian Influenza and other highly infectious diseases. Absent from the list of 55 concerns presented by Soisontes (2017) was the issue of particulate matter emission. Correspondingly, Vaarst et al. (2015) discussed many similar environmental issues as discussed in our paper, however, the impact of emissions of ammonia and particulate matter on the environment and the neighbouring community was not included. A possible reason is that the challenges related to particulate matter and ammonia relate to the high densities of livestock and people in the Netherlands, making it a rather context specific issue. Nevertheless, several recent papers from the USA have addressed particulate matter and ammonia, which suggests that the issue is increasingly recognized and studied (Mench and Rodenburg, 2018; Place, 2018; Shepherd et al., 2015).

In other studies on egg production, water and/or biodiversity have been included as sustainability issues (MacLeod, 2011; Soisontes, 2017; Vaarst et al., 2015; van Asselt et al., 2015). Although stakeholders mentioned resource use and land use, which can be connected to water and biodiversity, both issues were not explicitly mentioned by stakeholders as key for sustainable egg production in the Netherlands. As Dutch poultry farms generally have limited land, often only for the outdoor access, biodiversity of on-farm land use might not be recognized as an issue. Nevertheless, getting insight in the sustainability impact of egg production should also include off-farm impact on biodiversity and water resources, in particular those associated to feed production (Wilting and van Oorschot, 2017).

Several studies have looked at sustainability issues in Dutch egg production (Dekker et al., 2011; Mollenhorst et al., 2006; Mollenhorst and de Boer, 2004; van Asselt et al., 2015). Although there are many similarities with the issues mentioned in these papers (e.g. animal welfare, animal health, greenhouse gas emissions, resource use, farm income), sustainability issues related to the broader context (e.g. feed-food competition, societal support, public health impact of emissions, and human consumption of animal protein) were generally not included. Instead, these studies focused on assessing differences between housing systems and showed how each housing system provides certain advantages and disadvantages.

4.1. Moving towards sustainable egg production in the Netherlands

The interlinkages between the sustainability challenges discussed in this paper demonstrate the complexity of decision making towards sustainable egg production. Insight in these interlinkages and associated synergies and trade-offs between and within environmental, social and economic sustainability issues are, however, relevant to the development and implementation of innovations and policies for sustainable development of the egg sector (Bernués et al., 2011). Moreover, it explains why stakeholders might disagree on solution pathways, for example, when one stakeholder values outdoor access and another wants to minimize animal health risks, or when one stakeholder aims to reduce their carbon footprint and another wants to improve animal welfare. So, how to move forward?

As expressed by the interviewees, improving animal welfare conditions in egg production has been a dominant issue in the last decades. Animal welfare, and especially outdoor access is highly valued by society (Bos et al., 2018; Busch et al., 2018; Janssen et al., 2016; Van Loo et al., 2014; Żakowska-Biemans and Tekień, 2017). The attention for animal welfare is especially recognizable in market initiatives. Retailers have embraced initiatives contributing to higher standards of animal welfare such as NGO-led certification (e.g. Better Life certification (Toschi Maciel and Bock, 2013)), novel housing systems (e.g. Rondeel (Klerkx et al., 2012)), or defined their own criteria (e.g. ban on eggs from enriched cage and barn systems). Nevertheless, the dominant focus on animal welfare has also received criticism: "*While supermarkets* support *the development of new markets for animal welfare friendly products* (Miele and Lever, 2013) *in partnership with NGOs in some instances* (Miele and Lever, 2014)*, their power is such that they continue to exploit nature and the workers producing such products* (Gouveia and Juska, 2002; Lawrence, 2012; Lever and Milbourne, 2015)." (Lever and Evans, 2017). Several recent initiatives have aimed to address other sustainability issues. For example, supermarket Lidl has committed to addressing environmental issues by supporting the development of the Kipster farm and changing to white eggs for environmental reasons (Schotman, 2019).

Such private initiatives are considered a powerful instrument to address sustainability issues (Hörisch, 2018; Rueda et al., 2017). Nevertheless, as seen before, initiatives aimed at addressing a specific sustainability issue can result in trade-offs with other issues. Moreover, as pointed out by Rueda et al. (2017) there is no or little incentive for addressing an issue without consumers and civil society awareness. This highlights the importance of consumers being aware and well informed about the impact of their consumption and the consequences of production methods (Vaarst et al., 2015). This is challenging given the increasingly globalized food system and rapid decrease in the number of farms. As a result, there is an increasing disconnect between where food is produced and consumed. Consumers are consequently increasingly separated from the impact of their dietary choices (Davis et al., 2016).

Enabling consumers to make well-informed choices requires a certain transparency through the chain (Vaarst et al., 2015). An often proposed solution is the use of certification schemes or labels to communicate how animals have been kept (Busch et al., 2018; Heerwagen et al., 2015; Poore and Nemecek, 2018). The use of private labels has increased rapidly over the past decades (Boström et al., 2015; Scrinis et al., 2017). Although they can be successful in providing information on, for example, animal welfare conditions, they do not often include trade-offs with other sustainability issues (Lever and Evans, 2017). Moreover, concerns regarding the credibility, validity, implementation, transparency and power relations in certification schemes have been raised (Boström et al., 2015; de Olde et al., 2018; Lundmark et al., 2018). Moving towards sustainable consumption therefore requires transparency and responsibility across the chain.

Our results revealed the complex interaction of sustainability challenges in the Dutch egg sector. Many sustainability issues and innovations are linking the sector to its environment and to society. Steps towards sustainable egg production therefore require careful consideration of sustainability challenges and its trade-offs while making use of multi-stakeholder dialogue and joint commitments. The challenge is not to be overwhelmed by this complexity but to embrace it by identifying and analysing small wins, meaningful improvements, and mechanisms that can accumulate these into transformative change (Termeer and Dewulf, 2018). Such an approach can energize stakeholders in taking steps towards a more sustainable egg sector. This energy is needed to develop and maintain the commitment of a wide range of stakeholders to a transformation towards a more sustainable egg sector. Experimenting and sharing experiences with innovations, such as the ones presented in this paper, plays a crucial role in this process.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

E.M. de Olde: Conceptualization, Methodology, Investigation, Writing - review & editing. **A. van der Linden:** Investigation, Writing - review & editing. **L.D. olde Bolhaar:** Data curation, Investigation. **I.J.M. de Boer:** Conceptualization, Supervision, Funding acquisition.

Acknowledgements

We would like to thank all interviewees for their willingness to cooperate in this research. We thank J. de Moel and L. Verheijen for their contribution to the transcription of the interviews. This research was part of the AnimalFuture project (http://animalfuture.eu) which has been funded by ANR (France), BMLFUW (Austria), BMEL (Germany), NWO (the Netherlands), FCT (Portugal), INIA (Spain) and DEFRA (UK) as a part of the ERA-Net Cofund SusAn (grant agreement number 696231) under the EU research and innovation programme Horizon 2020.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.120974.

References

Agrimatie, 2018. Stalsystemen - leghennenhouderij. http://www.agrimatie.nl/ThemaResultaat.aspx?subpubID=2232&themaID=2270&indicatorID=2098. Accessed 18-12-2018 2018.

Beerens, N., Koch, G., Heutink, R., Harders, F., Vries, D.P.E., Ho, C., Bossers, A., Elbers, A., December 2017. Novel highly pathogenic avian influenza A(H5N6) virus in The Netherlands. Emerg. Infect. Dis. 24 (4), 770–773.

Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., Casasús, I., 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: synergies and trade-offs. Livest. Sci. 139 (1), 44–57.

Billen, P., Costa, J., Van der Aa, L., Van Caneghem, J., Vandecasteele, C., 2015. Electricity from poultry manure: a cleaner alternative to direct land application. J. Clean. Prod. 96, 467–475.

Boogaard, B.K., Boekhorst, L.J.S., Oosting, S.J., Sørensen, J.T., 2011. Socio-cultural sustainability of pig production: citizen perceptions in The Netherlands and Denmark. Livest. Sci. 140 (1–3), 189–200.

Bos, J.F.F.P., Smit, A.L., Schröder, J.J., 2013. Is agricultural intensification in The Netherlands running up to its limits? NJAS - Wageningen J. Life Sci. 66, 65–73, 0.

Bos, J.M., van den Belt, H., Feindt, P.H., 2018. Animal welfare, consumer welfare, and competition law: the Dutch debate on the Chicken of Tomorrow. Animal Frontiers 8 (1), 20–26.

Boström, M., Jönsson, A.M., Lockie, S., Mol, A.P.J., Oosterveer, P., 2015. Sustainable and responsible supply chain governance: challenges and opportunities. J. Clean. Prod. 107, 1–7.

Bouwstra, R., Gonzales, J.L., de Wit, S., Stahl, J., Fouchier, R.A.M., Elbers, A.R.W., 2017. Risk for low pathogenicity avian influenza virus on poultry farms, The Netherlands, 2007-2013. Emerg. Infect. Dis. 23 (9), 1510–1516.

Busch, G., Gauly, M., Spiller, A., 2018. Opinion paper: what needs to be changed for successful future livestock farming in Europe? Animal 12 (10), 1999–2001.

Busch, G., Spiller, A., 2018a. Consumer acceptance of livestock farming around the globe. Animal Frontiers 8 (1), 1–3.

Busch, G., Spiller, A., 2018b. Pictures in public communications about livestock farming. Animal Frontiers 8 (1), 27–33.

Castellari, E., Soregaroli, C., Venus, T.J., Wesseler, J., 2018. Food processor and retailer non-GMO standards in the US and EU and the driving role of regulations. Food Pol. 78, 26–37.

CBS, 2016. Op Meeste Boerderijen Geen Bedrijfsopvolger. Centraal Bureau voor de Statistiek, Den Haag/Heerlen.

CBS, 2017. Landbouw; gewassen, dieren en grondgebruik naar hoofdbedrijfstype, regio. https://www.cbs.nl/nl-nl/economie/landbouw. Accessed 06-06-2017 2017.

CBS, 2018a. Landbouw; biologisch, gewassen, dieren, national, 2011-2017. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/81517ned/table?dl=BB7F. Accessed 18-12-2018 2018.

CBS, 2018b. Landbouw; gewassen, dieren en grondgebruik naar hoofdbedrijfstype, regio. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/80783ned/table?dl=15236. Accessed 06-12-2018 2018.

David, B., Moe, O.R., Michel, V., Lund, V., Mejdell, C., 2015. Air quality in alternative housing systems may have an impact on laying hen welfare. Part I—Dust. Animals 5 (3).

Davis, K.F., Gephart, J.A., Emery, K.A., Leach, A.M., Galloway, J.N., D'Odorico, P., 2016. Meeting future food demand with current agricultural resources. Global Environ. Change 39, 125–132.

De Boer, I.J.M., Van Ittersum, M.K., 2018. Circularity in Agricultural Production. Wageningen University & Research, Wageningen, the Netherlands, p. 72.

De Olde, E.M., Carsjens, G.J., Eilers, C.H.A.M., 2016. The role of collaborations in the development and implementation of sustainable livestock concepts in The Netherlands. Int. J. Agric. Sustain. 1–16.

de Olde, E.M., Sautier, M., Whitehead, J., 2018. Comprehensiveness or implementation: challenges in translating farm-level sustainability assessments into

action for sustainable development. Ecol. Indicat. 85, 1107–1112.
De Vries, M., De Boer, I.J.M., 2010. Comparing environmental impacts for livestock products: a review of life cycle assessments. Livest. Sci. 128 (1–3), 1–11.
Dekker, S.E.M., de Boer, I.J.M., Vermeij, I., Aarnink, A.J.A., Koerkamp, P.W.G.G., 2011. Ecological and economic evaluation of Dutch egg production systems. Livest. Sci. 139 (1–2), 109–121.
Eurostat, 2017. Trade in eggs in the EU. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/EDN-20171013-1?inheritRedirect=true. Accessed 29-10-2018 2018.
FAO, 2016. FAOSTAT database collections. http://faostat.fao.org. Accessed 24/07/2018 2018.
Finfgeld-Connett, D., 2014. Use of content analysis to conduct knowledge-building and theory-generating qualitative systematic reviews. Qual. Res. 14 (3), 341–352.
Freidl, G.S., Spruijt, I.T., Borlée, F., Smit, L.A.M., van Gageldonk-Lafeber, A.B., Heederik, D.J.J., Yzermans, J., van Dijk, C.E., Maassen, C.B.M., van der Hoek, W., 2017. Livestock-associated risk factors for pneumonia in an area of intensive animal farming in The Netherlands. PloS One 12 (3), e0174796.
Friese, S., 2013. ATLAS. Ti 7 User Guide and Reference. ti Scientific Software Development GmbH, Berlin: ATLAS.
Gonzales, J.L., Stegeman, J.A., Koch, G., de Wit, S.J., Elbers, A.R.W., 2013. Rate of introduction of a low pathogenic avian influenza virus infection in different poultry production sectors in The Netherlands. Influenza and Other Respiratory Viruses 7 (1), 6–10.
Gouveia, L., Juska, A., 2002. Taming nature, taming workers: Constructing the separation between meat consumption and meat production in the U.S. Sociol. Rural. 42 (4), 370–390.
Grandin, T., 2014. Animal welfare and society concerns finding the missing link. Meat Sci. 98 (3), 461–469.
Gremmen, B., Bruijnis, M.R.N., Blok, V., Stassen, E.N., 2018. A public survey on handling male chicks in the Dutch egg sector. J. Agric. Environ. Ethics 31 (1), 93–107.
Heederik, D.J.J., 2018. Het gebruik van antibiotica bij landbouwhuisdieren in 2017. Trends, benchmarken bedrijven en dierenartsen. Autoriteit Diergeneesmiddelen, Utrecht, the Netherlands., pp. 1–96. Report number: SDa/1152/2018.
Heerwagen, L.R., Mørkbak, M.R., Denver, S., Sandøe, P., Christensen, T., 2015. The role of quality labels in market-driven animal welfare. J. Agric. Environ. Ethics 28 (1), 67–84.
Holt, P.S., Davies, R.H., Dewulf, J., Gast, R.K., Huwe, J.K., Jones, D.R., Waltman, D., Willian, K.R., 2011. The impact of different housing systems on egg safety and quality 1. Poultry Sci. 90 (1), 251–262.
Hörisch, J., 2018. How business actors can contribute to sustainability transitions: a case study on the ongoing animal welfare transition in the German egg industry. J. Clean. Prod. 201, 1155–1165.
IJzermans, C.J., Smit, L.A.M., Heederik, D.J.J., Hagenaars, T.J., 2018. Veehouderij en gezondheid omwonenden III: longontsteking in de nabijheid van geiten- en pluimveehouderijen; actualisering van gegevens uit huisartspraktijken 2014 - 2016. Nivel, Utrecht.
Janssen, M., Rödiger, M., Hamm, U., 2016. Labels for animal husbandry systems meet consumer preferences: results from a meta-analysis of consumer studies. J. Agric. Environ. Ethics 29 (6), 1071–1100.
Jonges, M., van Leuken, J., Wouters, I., Koch, G., Meijer, A., Koopmans, M., 2015. Wind-mediated spread of low-pathogenic avian influenza virus into the environment during outbreaks at commercial poultry farms. PloS One 10 (5), e0125401.
Kalkowska, D.A., Boender, G.J., Smit, L.A.M., Baliatsas, C., Yzermans, J., Heederik, D.J.J., Hagenaars, T.J., 2018. Associations between pneumonia and residential distance to livestock farms over a five-year period in a large population-based study. PloS One 13 (7), e0200813.
Kipster, 2019. Kipster. https://www.kipster.farm/. Accessed 12-02-2020 2020.
Klerkx, L., Van Bommel, S., Bos, A.P., Holster, H., Zwartkruis, J.V., Aarts, N., 2012. Design process outputs as boundary objects in agricultural innovation projects: functions and limitations. Agric. Syst. 113, 39–49.
Koch, G., Elbers, A.R.W., 2006. Outdoor ranging of poultry: a major risk factor for the introduction and development of High-Pathogenicity Avian Influenza. NJAS - Wageningen J. Life Sci. 54 (2), 179–194.
Koopmans, M., Wilbrink, B., Conyn, M., Natrop, G., van der Nat, H., Vennema, H., Meijer, A., van Steenbergen, J., Fouchier, R., Osterhaus, A., Bosman, A., 2004. Transmission of H7N7 avian influenza A virus to human beings during a large outbreak in commercial poultry farms in The Netherlands. Lancet 363 (9409), 587–593.
Lawrence, F., 2012. Workers who collected freedom food chickens 'were trafficked and beaten'. Guardian. October 29: accessed December 2, 2015.
Lever, J., Evans, A., 2017. Corporate social responsibility and farm animal welfare: towards sustainable development in the food industry? In: Idowu, S.O., Vertigans, S. (Eds.), Stages of Corporate Social Responsibility: from Ideas to Impacts. Springer International Publishing, Cham, pp. 205–222.
Lever, J., Milbourne, P., 2015. The structural invisibility of outsiders: The role of migrant labour in the meat-processing industry. Sociology 1–17. https://doi.org/10.1177/0038038515616354. Published on-line first, December 23, 2015.
Lundmark, F., Berg, C., Röcklinsberg, H., 2018. Private animal welfare standards—opportunities and risks. Animals 8 (1), 4.
MacLeod, M.G., 2011. 19 - Environmental Sustainability of Egg Production and Processing, Improving the Safety and Quality of Eggs and Egg Products. Woodhead Publishing, pp. 445–462.
Mench, J.A., Rodenburg, T.B., 2018. 10 - sustainability of laying hen housing systems. In: Mench, J.A. (Ed.), Advances in Poultry Welfare. Woodhead Publishing, pp. 199–225.
Miele, M., Lever, J., 2013. Civilizing the market for welfare friendly products in Europe? The techno-ethics of the Welfare Quality Assessment. Geoforum 48, 63–72.
Miele, M., Lever, J., 2014. Improving animal welfare in Europe: Cases of comparative bio-sustainabilities. In: Marsden, T., Morely, A. (Eds.), Sustainable food systems: Building a new paradigm. Earthscan, London.
Min, S., Kalwani, M.U., Robinson, W.T., 2006. Market pioneer and early follower survival risks: a contingency analysis of really new versus incrementally new product-markets. J. Market. 70 (1), 15–33.
Ministerie van Landbouw, N.e.V., 2018. In: Ministerie van Landbouw, N.e.V. (Ed.), Besluit van de Minister van Landbouw, Natuur en Voedselkwaliteit van 4 april 2018, nr. 18045099, houdende inwilliging AVV-verzoek pluimveesector. Staatscourant, The Hague, the Netherlands.
Mollenhorst, H., Berentsen, P.B.M., de Boer, I.J.M., 2006. On-farm quantification of sustainability indicators: an application to egg production systems. Br. Poultry Sci. 47 (4), 405–417.
Mollenhorst, H., de Boer, I.J.M., 2004. Identifying sustainability issues using participatory SWOT analysis:A case study of egg production in The Netherlands. Outlook Agric. 33 (4), 267–276.
Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., Gerber, P., 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. Global Food Security 14, 1–8.
Mottet, A., Tempio, G., 2017. Global poultry production: current state and future outlook and challenges. World Poultry Sci. J. 73 (2), 245–256.
Muhr, T., 1991. ATLAS/ti — a prototype for the support of text interpretation. Qual. Sociol. 14 (4), 349–371.
Parodi, A., Leip, A., De Boer, I.J.M., Slegers, P.M., Ziegler, F., Temme, E.H.M., Herrero, M., Tuomisto, H., Valin, H., Van Middelaar, C.E., Van Loon, J.J.A., Van Zanten, H.H.E., 2018. The potential of future foods for sustainable and healthy diets. Nature Sustainability 1 (12), 782–789.
Pettersson, I.C., Weeks, C.A., Wilson, L.R.M., Nicol, C.J., 2016. Consumer perceptions of free-range laying hen welfare. Br. Food J. 118 (8), 1999–2013.
PEV, 2020. Praktijkcentrum emissiereductie veehouderij. https://www.praktijkcentrumemissiereductie.nl/. Accessed 12-02-2020 2020.
Place, S.E., 2018. 4 - animal welfare and environmental issues. In: Mench, J.A. (Ed.), Advances in Agricultural Animal Welfare. Woodhead Publishing, pp. 69–89.
Poore, J., Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. Science 360 (6392), 987–992.
Poulsen, M.N., Pollak, J., Sills, D.L., Casey, J.A., Nachman, K.E., Cosgrove, S.E., Stewart, D., Schwartz, B.S., 2018. High-density poultry operations and community-acquired pneumonia in Pennsylvania. Environmental Epidemiology 2 (2), e013.
Rueda, X., Garrett, R.D., Lambin, E.F., 2017. Corporate investments in supply chain sustainability: selecting instruments in the agri-food industry. J. Clean. Prod. 142, 2480–2492.
Schotman, T., 2019. Lidl Stapt over Op Uitsluitend Witte Eieren Met Minimaal 1 Ster Van Het Beter Leven Keurmerk, Pluimveeweb. Agrio Uitgeverij B.V., 's Heerenberg, the Netherlands.
Schouten, C., 2018. Landbouw, natuur en voedsel: waardevol en verbonden. Ministerie van Landbouw, Natuur en Voedselkwaliteit, The Hague.
Scrinis, G., Parker, C., Carey, R., 2017. The caged chicken or the free-range egg? The regulatory and market dynamics of layer-hen welfare in the UK, Australia and the USA. J. Agric. Environ. Ethics 30 (6), 783–808.
Shepherd, T.A., Zhao, Y., Li, H., Stinn, J.P., Hayes, M.D., Xin, H., 2015. Environmental assessment of three egg production systems — Part II. Ammonia, greenhouse gas, and particulate matter emissions. Poultry Sci. 94 (3), 534–543.
Smit, L.A.M., Boender, G.J., de Steenhuijsen Piters, W.A.A., Hagenaars, T.J., Huijskens, E.G.W., Rossen, J.W.A., Koopmans, M., Nodelijk, G., Sanders, E.A.M., Yzermans, J., Bogaert, D., Heederik, D., 2017. Increased risk of pneumonia in residents living near poultry farms: does the upper respiratory tract microbiota play a role? Pneumonia 9 (1), 3.
Soisontes, S., 2017. Concerns about sustainability in the poultry industry: a comparative Delphi study in Germany and Thailand. World Poultry Sci. J. 73 (4), 886–903.
Sorgdrager, W., 2018. Onderzoek Fipronil in Eieren. Commissie Onderzoek Fipronil in Eieren. Enschede, The Netherlands.
Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., Haan, C.d., 2006. Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization of the United Nations (FAO), Rome.
Stevens, T.M., Aarts, N., Termeer, C.J.A.M., Dewulf, A., 2018. Social media hypes about agro-food issues: activism, scandals and conflicts. Food Pol. 79, 23–34.
Swanson, J.C., Lee, Y., Thompson, P.B., Bawden, R., Mench, J.A., 2011. Integration: valuing stakeholder input in setting priorities for socially sustainable egg production 1. Poultry Sci. 90 (9), 2110–2121.
Termeer, C.J.A.M., Dewulf, A., 2018. A small wins framework to overcome the evaluation paradox of governing wicked problems. Policy and Society 1–17.
Toschi Maciel, C., Bock, B.B., 2013. Modern politics in animal welfare: the changing character of governance of animal welfare and the role of private standards. Int. J. Sociol. Agric. Food 20 (2), 219–235.
Vaarst, M., Steenfeldt, S., Horsted, K., 2015. Sustainable development perspectives of poultry production. World Poultry Sci. J. 71 (4), 609–620.

van Asselt, E.D., van Bussel, L.G.J., van Horne, P., van der Voet, H., van der Heijden, G.W.A.M., van der Fels-Klerx, H.J., 2015. Assessing the sustainability of egg production systems in The Netherlands. Poultry Sci. 94 (8), 1742–1750.

van Asselt, M., Kemp, B., Stassen, E.N., Poortvliet, P.M., Ekkel, E.D., 2017. Risk perceptions of public health and food safety hazards in poultry husbandry by citizens, poultry farmers and poultry veterinarians. Poultry Sci. 97 (2), 607–619.

van de Weerdt, R., Zuurbier, M., 2017. Naar Een Gezonde Lucht in Gelderland - Update 2017. Gezondheid Meewegen in Besluitvorming Fysieke Leefomgeving. Veiligheids- en Gezondheidsregio Gelderland-Midden, Arnhem, the Netherlands.

van der Merwe, D., Jordaan, A., van den Berg, M., 2019. Case report: fipronil contamination of chickens in The Netherlands and surrounding countries. Chemical hazards in foods of animal origin 363–373. Wageningen Academic Publishers.

van Dijk, C.E., Zock, J.-P., Baliatsas, C., Smit, L.A.M., Borlée, F., Spreeuwenberg, P., Heederik, D., Yzermans, C.J., 2017. Health conditions in rural areas with high livestock density: analysis of seven consecutive years. Environ. Pollut. 222, 374–382.

van Horne, P., van der Meulen, H., Wisman, A., 2017. Indicatie economische gevolgen fipronilaffaire voor de pluimveesector. Wageningen Economic Research, Wageningen, the Netherlands.

Van Loo, E.J., Caputo, V., Nayga, R.M., Verbeke, W., 2014. Consumers' valuation of sustainability labels on meat. Food Pol. 49, 137–150.

Van Zanten, H.H.E., Herrero, M., Van Hal, O., Röös, E., Muller, A., Garnett, T., Gerber, P.J., Schader, C., De Boer, I.J.M., 2018. Defining a land boundary for sustainable livestock consumption. Global Change Biol. 24 (9), 4185–4194.

Wilting, H.C., van Oorschot, M.M.P., 2017. Quantifying biodiversity footprints of Dutch economic sectors: a global supply-chain analysis. J. Clean. Prod. 156, 194–202.

Winkel, A., Mosquera, J., Groot Koerkamp, P.W.G., Ogink, N.W.M., Aarnink, A.J.A., 2015. Emissions of particulate matter from animal houses in The Netherlands. Atmos. Environ. 111, 202–212.

Żakowska-Biemans, S., Tekień, A., 2017. Free range, organic? Polish consumers preferences regarding information on farming system and nutritional enhancement of eggs: a discrete choice based experiment. Sustainability 9 (11), 1999.