



Social life cycle assessment in current and future Norwegian livestock production

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Abstract

Purpose This study is a social life cycle assessment (S-LCA) of per capita consumption of animal protein in Norway in 2019. The animal protein consisted of milk, beef, pork, poultry and egg. Based on the 2019 results, two scenarios, TrendProd and ChangeProd, were qualitatively assessed. The TrendProd scenario is a continuation of the current trend towards highly efficient livestock production, whilst ChangeProd focuses on using livestock feed based on bioresources that are unsuitable for human consumption.

Methods The assessment of current livestock production followed the updated version of the social LCA guidelines by UNEP (2020). A survey amongst stakeholders was conducted for the selection of subcategories. The product system was divided into the following steps: imported feed, domestic off-farm feed, livestock production, manufacturing, distribution and use. A total of 25 subcategories across six stakeholder groups (i.e. workers, local community, society, value chain actors, consumers and children) were included in the assessment. A reference scale approach was used with a scale from 1 to 4. The assessment included quantitative and qualitative data from statistics, indices, surveys, etc. The social performance of the scenarios was assessed by the authors' expert evaluation using the Delphi approach, comparing performance of indicators relative to the current production.

Results and discussion The life cycle for the current Norwegian livestock production had an acceptable or high social performance for 17 of the selected subcategories. Five subcategories had a low performance (fair salary, equal opportunities, animal welfare, food security, promoting social responsibility) and three had a very low performance (health and safety, cultural heritage, fair competition). The assessment of the scenarios indicated that anticipated improvements in skills and technology were key drivers for maintaining or enhancing social performance in certain subcategories. The use of activity variables for measuring the relative importance of each unit process is recommended as it reflects actual distribution and is consistent with the method of environmental LCA.

Conclusions Overall, the social life cycle assessment of current livestock production demonstrated high social performance. A stakeholders' survey resulted in a new subcategory, 'food security', which served to include societal concern for self-sufficiency and food security in social LCA. Limitations and uncertainties of the study have also been identified, some relating to data and choice of indicators and others to the application of method, e.g. activity variables, development of reference scale and aggregation of results.

Keywords Social LCA · Livestock production · Agriculture · Future farming · Survey · Sustainability

1 Introduction

The world's population reached 8 billion in 2022 (United Nations 2022b), which is a doubling since 1974. Although the population rate is decreasing, it remains positive,

leading to a continued increase in food demand. At the same time, a more unstable climate, marked by floods and droughts, can make food production more vulnerable. Existing research and discussions mainly focus on environmental issues, yet it is important to include social aspects linked to food production. Several of the UN's sustainability goals (UNEP 2015) are aimed at social sustainability and the same applies to sustainable development, which is defined as a 'development that meet the needs of the

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present without compromising the ability of future generations to meet their own needs' (WCED 1987). Sustainable development means a change from the current state to a more sustainable state in the future (Bardalen et al. 2020). Therefore, the time frame is important to include when considering various future scenarios to provide information on whether the development is moving in a more sustainable direction. Sustainability does not have a fixed, unchanged definition and the same applies to the social part of sustainability; it is a concept that develops over time and between places (Dempsey et al. 2011).

Life cycle assessment (LCA) was originally applied to assess environmental impacts of products and processes at each step of their life cycle. The LCA methodology was further developed for social LCA (S-LCA), integrating the modelling techniques and systematic assessment processes of LCA combined with methods from social sciences. The S-LCA guidelines were first published by UNEP/SETAC in 2009 and updated in a revised edition in 2020 (UNEP 2020). Associated methodological sheets for further guidance were published in 2021 (UNEP 2021). S-LCA consists of four phases: goal and scope of a study, collecting data, assessing the risks and potential impacts, and interpretation of the results. The S-LCA guidelines provide several different approaches and examples and lead to further references on, e.g. indicator development.

Although there is still a long way ahead until S-LCA's scientific maturity (Ramos Huarachi et al. 2020), the methodology has been gradually developed and is increasingly used for the assessment of different products or organisations. Several methodological reviews (Pollok et al. 2021; Tragnone et al. 2022) and social LCA case studies have been carried out, such as for biodiesel (Manik et al. 2013), the automotive industry (Zanchi et al. 2018), a slaughter concept (Valente et al. 2023) and waste wool (Martin and Herlaar 2021). Yet, there is only a small number of case studies of social LCA in food production in general (Mancini et al. 2023) and more specifically for livestock production, i.e. milk in Ireland (Chen and Holden 2017), beef production in Mexico (Rivera-Huerta et al. 2019) and South Western Europe (Zira et al. 2023), pig production in Sweden (Zira et al. 2020) and egg production in Canada (Pelletier 2018). An estimate of the social footprint of EU food consumption (Mancini et al. 2023) showed that vegetables, fruits and rice are major contributors to social risks. This contrasts with environmental assessments of food, which revealed a higher impact of animal-based products, in particular meat and dairy products. The aforementioned studies had a large variety in the application of methodology, inclusion of stakeholders and data collection, which indicates that S-LCA studies are case specific. In a literature review of S-LCA studies of agri-food products (Arcese et al. 2023), the lack of data as well as

the need to include all relevant stakeholders in the entire agri-food chain is highlighted as the most important findings. Desiderio et al. (2022) examined tools and indicators for measuring social sustainability aspects. Most of the tools and indicators, especially the quantitative ones, were aimed at the primary production and fewer for the rest of the value chain.

Farming in different parts of the world is highly interdependent due to the prices for farm products being largely determined by global markets. In high-income countries, the employment rates in agriculture are declining, and the farm size and the productivity per agricultural worker are increasing (European Commission, 2013, 2021; Giller et al. 2021). The structural changes in agriculture towards intensification, focusing on high efficiency and high output, have developed over time. In addition, the number of farms in the EU has been declining (European Commission, 2013) in which Norway follows the same trend. The total number of farms has halved since 2000 and the number of dairy cows has decreased, however, with increased milk yield per cow (NDHRS 2020).

Agricultural production is diverse within sectors, regions, and countries. This is due to different natural, structural, market and political conditions, leading to different use of technologies and practices. Sauer and Moreddu (2020) analysed the relationship between productivity and sustainability (measured by, e.g. the intensity in fertiliser, chemical or fuel use and animal stocking density) in 13 countries for different farm types. The correlation between productivity and environmental sustainability was mostly negative for dairy, pig, and poultry farms, i.e. farms that have a high productivity are less sustainable, but for beef, sheep and crop farms, there was no clear correlation. This implies that to achieve both sustainable development and increased efficiency in agriculture, it might be necessary to change the current production pattern, especially for dairy, pig, and poultry farms. Important priorities for the transition to a more sustainable food system are increased utilisation of by-products and food waste and using livestock mainly to convert bioresources that humans are unable to eat into valuable food products (de Boer and van Ittersum 2018; Van Zanten et al. 2019). To achieve a more sustainable food production, there is a need for new technology and digitalisation and increasing requirements for new skills that combine agronomy and animal husbandry with technology (Pettersen and Kårstad 2021).

Recognising the need for a transition of the food system and the importance of social sustainability, this study examines the social sustainability of current and future livestock production, using Norway as a case study. The application of the S-LCA method to current livestock production is described, with results presented and discussed. It also includes an assessment of future scenarios to address the time frame by identifying future generations' need for food,

whilst aiming to reduce greenhouse gas emissions, improve farm animal welfare and enhance circular food production. The future scenarios were evaluated using the Delphi method, based on the findings of the current production.

2 Material and methods

2.1 Goal and scope

The goal of the study was to assess the social sustainability of current livestock production in Norway and use the findings as a basis for a qualitative comparison with two future scenarios for livestock production in 2040 in Norway, TrendProd and ChangeProd. The TrendProd scenario focused on reducing climate impact and enhancing animal welfare, whilst ChangeProd included additional requirements on circularity where feed could only be produced from bioresources that were unsuitable for human consumption (see Sect. 2.2).

The scope was livestock protein production in Norway, including milk, beef, pork, poultry and egg production for the whole life cycle from cradle to grave (Fig. 1). Norway has a goal of increasing self-sufficiency in food, although the climatic and natural conditions set certain limitations. Protein production was chosen because it is limited, whether it concerns plant protein for feed protein or protein for human consumption. Energy-rich food and feed are available to a greater extent. The current production year should ideally

have been 2020, but due to the pandemic, 2019 was used instead.

The functional unit was the average amount of domestically produced animal protein per capita in Norway. The mass-based reference flow was calculated by converting the animal protein into wholesale amounts of each livestock product and the associated feed requirements. The reference flow was then converted into activity units, e.g. worker-hours required for producing the reference flow; see Sect. 2.5. The composition was based on protein content in domestic livestock products in the current production (Animalia 2020; NDHRS 2020); see Table 1. For the scenarios, the livestock production was based on what it would be possible to produce in 2040 with the limitations and assumptions set in the scenarios (see Sect. 2.2). The calculations of the amount of protein produced for 2040 have considered a population increase of approximately 10%. Since it was assumed that livestock production in ChangeProd was based on domestic feed alone, where only surplus grain was used for feed, the livestock protein production was reduced compared to current production. The reduced animal protein production was assumed to be covered by domestic grain and vegetable production to maintain a constant amount of protein per capita. The milk and egg production quantities were constant in both scenarios. In ChangeProd, beef from suckler cows and chicken were completely omitted; see Sect. 2.2.

The study followed the updated version of the Guidelines for Social Life Cycle Assessment of Products and Organizations 2020 (UNEP 2020) for the current production. As suggested by these guidelines, the following stakeholder

Stakeholders groups Life cycle steps	Workers 	Local community 	Society 	Value chain actors 	Consumers and children 
Imported feed	✓	✓	✓		
Domestic feed production	✓	✓	✓	✓	
Livestock production	✓	✓	✓	✓	
Manufacturing		✓	✓	✓	
Wholesale and retail			✓	✓	
Use			✓		✓

Fig. 1 General description of the included life cycle steps and which stakeholder groups that are defined engaged in each step

Table 1 Amount of animal protein (kg per capita) produced in Norway, distributed amongst livestock products, for the current production and the scenarios TrendProd and ChangeProd in 2040 (% distribution in brackets). TrendProd follows the current protein level per capita. ChangeProd assumes changed livestock production, resulting in a reduced total production

kg protein per capita	Current production and TrendProd		ChangeProd	
Dairy products	10.6	(50%)	10.6	(62%)
Beef from dairy cattle	1.8	(8%)	2.4	(14%)
Beef from suckler cow	1.0	(5%)	–	–
Pork	3.9	(18%)	2.3	(13%)
Chicken	2.2	(10%)	–	–
Egg	1.8	(8%)	1.8	(11%)
Total	21.3	(100%)	17.1	(100%)

groups were included: *workers, local community, society, value chain actors, consumers and children*. A participatory approach was used to increase the legitimacy of the assessment (De Luca et al. 2017; Sureau et al. 2019) and extend the scope by involving a range of stakeholders for the selection of categories (Bouillass et al. 2021). Activity variables were used to measure the relative quantitative importance of different unit processes in the product system (see Sect. 2.5). The described scenarios were included as a qualitative assessment using the Delphi approach and did not follow the S-LCA method from UNEP.

2.2 Description of current production and scenarios

In the current production, farms with livestock production are not distributed evenly across the Norwegian country. This is partly due to geographic and cultural differences but also due to political initiatives to support farming in remote areas and to achieve an adequate distribution of manure. Politically, differentiated subsidies have contributed to channelling livestock production in areas that are most suitable from an agricultural perspective. Additionally, milk quotas are used to regulate milk production and licences, which set limits on the number of animals per farm in pig and poultry production.

The scenarios were developed to illustrate two possible directions of the livestock production. The TrendProd scenario describes a continuation of the current trend of highly efficient livestock production, including structural and technological development in agriculture, and the associated parts of the food supply chain. Feed concentrates are prioritised when allocating grain crops and therefore a large proportion of grains for food is assumed to be imported as they are in the current production. Furthermore, it is assumed that by 2040, the total number of farms will be halved, and the

farms will be larger and concentrated in the more productive areas, both in terms of the number of livestock and the area for feed production. The number of dairy cows per farm will increase by 65% compared to current production. Chickens and laying hens will be reared in a free-run housing system due to the assumption of increased focus on animal welfare. Pig production will be completely converted to a specific pathogen-free (SPF) health regime. The number of poultry and pigs per farm is regulated by licences for concentrate-based livestock farming, but it is assumed that the licence limits will have increased somewhat by 2040.

ChangeProd is based on the principles of only using bioresources that humans are unable to eat for livestock feed. Political instruments are assumed necessary to achieve this scenario where the goal is increased circularity in animal production. Only domestic feed ingredients are used in animal production, where grain is primarily used for food and only surplus grain is used for feed. Concentrate-based livestock production will therefore be significantly reduced. Pig production utilises the surplus grain, by-products, and food waste, and similarly to TrendProd, the production will be completely converted to SPF. The chicken production will cease due to low possibilities for utilising waste streams and by-products. In egg production, changes are introduced in current free-run systems, to reduce the high mortality for hens (Animalia 2020). An improved housing system with environmental enrichment such as oyster shells is used, changes are made to the breeding goals (Arndt et al. 2022), and requirements are introduced for better air quality with less dust and lower NH_3 levels (Vasdal et al. 2023). The limits on the number of animals per farm will still be regulated by licences for concentrate-based livestock farming, assuming the same number of pig and laying hens per farm as in current production. The number of dairy farms will be the same as in the current production, but due to a lower milk yield per cow, the number of dairy cows per farm will increase by 40%. Many of the farms in the less productive areas will still be in operation as there will be a greater emphasis on utilising grass resources, specifically in outfields consisting of natural wild vegetation, where forest and mountain terrain is not cultivated or fertilised. There will be no suckler cow production, but instead the combined milk and meat production will ensure a balanced production, with only a minor decrease in the beef production.

There are some common features for both scenarios. It is assumed that novel feed ingredients such as yeast, insects and grass protein are used to a great extent. Liquid manure is assumed to be processed in anaerobic digestion plants on large farms, whereas smaller farms deliver manure to central plants or large farms. The digestate is used as fertiliser on arable land. For details, see Table 2.

2.3 System boundaries and stakeholder groups

The life cycle was divided into the following steps: imported feed, domestic off-farm feed, livestock production, manufacturing, distribution, use. The imported feed was assumed to be produced in representative countries (Brazil, Canada, Latvia, Poland) as they account for a large part of feed imports. The other life cycle steps were based on Norwegian conditions. The livestock production included dairy cattle, suckler cow, pig, chicken and laying hen. The type of production is specified if applicable, otherwise ‘livestock production’ is used when it is referred to in general terms.

The cut-off criteria for the processes from cradle to use phase were defined in terms of quantity and working time contributions to the whole life cycle (Martínez-Blanco et al. 2014), e.g. production of fertilisers and pesticides, technical equipment, veterinarian, and social significance according to a social hot spot analysis of meat and dairy products used in the Social Hotspot database (Benoit Norris et al. 2019).

Each stakeholder group was assessed for the whole or parts of the product system. *Workers* were defined as those directly involved in imported and domestic feed production, farmers, and farm employees. Workers in the rest of the value chain were excluded because the working time was considered short per functional unit (see Sect. 2.1). *Local community* was limited to include residents who live near either foreign or domestic farms or food production companies. *Society* was here defined as the nation state and its institutions and population. *Value chain actors* could include many different actors, but in relevance to the goal and scope, this was limited to domestic farmers, food industry, wholesale, and retail. *Consumers* and *children* were defined as Norwegian consumers, buying and eating animal food products, and Norwegian children to whom marketing of the food products is directed (Fig. 1).

2.4 Selection of subcategories

The S-LCA guidelines by UNEP list a total of 40 subcategories distributed amongst the stakeholder groups. Selection of the subcategories to be included in the assessment was based on a stakeholder survey and a hotspot analysis.

The survey was sent to 53 Norwegian stakeholders in the value chain and received 28 responses from food and feed industries (7), farmers and workers’ organisations (4), authorities and county governors (6), consumer organisation (1), non-governmental organisations (7) and university and research institutes (3). The respondents rated social subcategories for their relevance to measure the social sustainability of food, using a scale from 1 (not relevant) to 4 (very relevant). Subcategories with an average score of 3 or higher (quite relevant or very relevant) were included in the study.

The subcategories were based on the S-LCA guidelines by UNEP (UNEP 2020) and were adapted and translated to suit Norwegian conditions. To improve clarity, the subcategories ‘safe and healthy living conditions’ and ‘secure living conditions’ were merged, resulting in 39 subcategories for assessment (see Table 3).

The respondents were invited to add subcategories that they thought were missing in the S-LCA guidelines. The suggested categories included mental health for farmers, food security, self-sufficiency, food sovereignty, solidarity, and market access. Each suggestion was carefully considered by the authors. ‘Mental health’ was considered relevant because, as it is a significant issue in agriculture compared to other sectors in Norway (Fremstad 2023). According to the description of ‘health and safety’ for *workers* in the S-LCA guidelines (UNEP 2021), the term health, in relation to work, includes the physical and mental elements affecting health, which are directly related to safety and hygiene at work. Therefore, ‘mental health’ was included as an additional indicator for this subcategory. ‘Food security’ involves food availability, access, utilisation, and stability, according to FAO (2006). The term is currently missing in the S-LCA methodology but includes relevant socio-economic aspects for the sustainability of food systems (Mancini et al. 2023). Food security is vital not only for developing countries experiencing food shortages and emergencies but also for ensuring a stable food supply in developed countries, especially in times of crisis. The topic was therefore considered relevant and was added to the stakeholder group *society*. Additional suggestions in terms of ‘self-sufficiency’, ‘food sovereignty’, and ‘solidarity’ were assessed as belonging to ‘food security’ and not included as separate subcategories. ‘Market access’ is already included in the subcategory ‘supplier relationship’ according to the S-LCA guidelines.

In addition to the survey, a hotspot analysis in the Social Hotspot Database (Benoit Norris et al. 2019) was carried out for dairy and meat products. The risk, expressed as medium risk hours equivalents (mrheq), distributed on the subcategories was ranked from highest to lowest and a cut-off of 75% of the total risk was used, i.e. the subcategories that were ranked below this cut-off were considered low risk and excluded in further analysis. By comparing results from the survey and the hotspot analysis, a total of 26 subcategories were included; see Table 3.

2.5 Activity variables

An activity variable is a measure of process activity related to process output and can be useful for measuring the relative quantitative importance of each unit process in the product system, according to S-LCA guidelines (UNEP 2020). The activity variable serves to convert the initially quantified mass-based reference flow within a product system into

Table 2 Description and key numbers of the current production and the scenarios in 2040; TrendProd following the current trend from 2019 onwards and ChangeProd assuming changed livestock production with increased circularity

Subject	Current production	TrendProd	ChangeProd
Domestic crops used for food	50% of wheat 5% of other grains	50% of wheat 5% of other grains	All wheat, oat, peas, faba beans, rapeseed oil
Domestic crops used for feed	Imported and domestic feed ingredients High-quality grass silage, no grazing in the outfields	Mainly domestic feed ingredients: Remaining 50% of wheat and 95% of other grains Grass silage and pasture, no grazing in the outfields	Only domestic feed ingredients: Barley and grass silage Grazing, semi-natural pasture and outfields
Residuals/by-products for feed	Food industry waste Rendered fat Crop by-products	Food industry waste Rendered fat, meat and bone meal Crop by-products	Food industry waste Rendered fat, meat and bone meal Crop, potato and vegetable residuals
Novel feed ingredients	None	Yeast, insect and gras protein	Yeast, insect and gras protein
Livestock production and rearing	Milk yield: 7973 kg FPCM ¹ Carcass per dairy cow: 260 kg Carcass per suckler cow: 335 kg Automatic milking system: 23% of the dairy farms; other milking systems: 77%	Milk yield: 10,487 kg FPCM ¹ Carcass per dairy cow: 298 kg Carcass per suckler cow: 345 kg Automatic milking system: 100% of the dairy farms	Milk yield: 6576 kg FPCM ¹ Carcass per dairy cow: 274 kg No beef cattle Automatic milking system: 50% of the dairy farms; other milking systems: 50%
Technology	Loose housing: 64% of the dairy farms Pigs: 20% SPF ² Chicken: free-run Laying hen: free-run	Loose housing: 100% of the dairy farms Pigs: 100% of SPF ² Chicken: free-run Laying hen: free-run	Loose housing: 100% of the dairy farms Pigs—100% of SPF ² No chicken production Laying hen: enriched free-run
	Fuel for agricultural machinery: fossil fuel Untreated manure used on arable land Mineral fertiliser produced by fossil gas	Fuel for agricultural machinery: biogas Digestate from anaerobic digestion of liquid manure used on arable land Mineral fertiliser produced by renewable electricity	Fuel for agricultural machinery: biogas Digestate from anaerobic digestion of liquid manure used on arable land Mineral fertiliser produced by renewable electricity
	Farms not evenly distributed, but still agriculture throughout the country	Number of farms halved and location only in the most productive areas, number of dairy cows per farm increased by 65%	Farm distribution, number of pigs and laying hens like in current production, number of dairy cows per farm increased by 40%
	Subsidies for livestock based on the number of animals, subsidies for small and medium-sized dairy farms, area subsidies, etc	Economic instruments for climate measures, increased efficiency, and domestic feed	Economic instruments for increased use of pasture, by-products, and residuals
Consumers	Following current diet	Willingness to make minor changes in the diet	Willingness to adapt the diet to what is available

¹ FPCM fat and protein corrected milk² SPF specific pathogen-free

Table 3 Selection of subcategories, based on stakeholder survey and social hotspot analysis. Categories which have an average score below 3 are not included in the assessment and are marked with italic

text. Score scale: not relevant (1), slightly relevant (2), quite relevant (3), and very relevant (4)

Stakeholder groups	Subcategories	Survey score	Cause of exclusion
Workers	Freedom of association and collective bargaining	3.6	
	Child labour	3.8	
	Fair salary	3.8	
	Working hours in accordance with current regulations	3.6	
	Forced labour	3.8	
	Equal opportunities/discrimination	3.5	
	Health and safety	3.9	
	<i>Social benefits and social security¹</i>	3.5	<i>Low risk in hot spot</i>
	Employment relationship and contract	3.6	
	Sexual harassment	3.6	
	Smallholders including farmers	3.5	
Local community	<i>Access to material resources</i>	2.8	<i>Not relevant for stakeholders</i>
	<i>Access to community services such as health services and education</i>	2.8	<i>Not relevant for stakeholders</i>
	<i>Migration of jobseekers</i>	2.4	<i>Not relevant for stakeholders</i>
	Cultural heritage	3.0	
	Safe and secure living conditions	3.5	
	<i>Respect for the rights of indigenous peoples</i>	3.6	<i>Low risk in hot spot</i>
	<i>Community engagement</i>	2.9	<i>Not relevant for stakeholders</i>
	Local employment	3.3	
Society	Public commitments to sustainability issues	3.2	
	<i>Contribution to economic development</i>	2.8	<i>Not relevant for stakeholders</i>
	<i>Prevention and mitigation of armed conflicts</i>	2.7	<i>Not relevant for stakeholders</i>
	<i>Technology development</i>	2.1	<i>Not relevant for stakeholders</i>
	Corruption	3.6	
	Animal welfare ²	3.7	
	Poverty alleviation	3.3	
	Food security	Added	
Value chain actors	Fair competition	3.2	
	Promoting social responsibility	3.1	
	Supplier relationship	3.2	
	<i>Respect for intellectual property rights</i>	2.8	<i>Not relevant for stakeholders</i>
	Distribution of income between suppliers and grocery trade ³	3.2	
Consumers	Health and safety	3.3	
	<i>Consumer satisfaction</i>	2.3	<i>Not relevant for stakeholders</i>
	<i>Consumer privacy</i>	2.9	<i>Not relevant for stakeholders</i>
	Transparency about working conditions and sustainability	3.8	
	End-of-life responsibility	3.4	
Children	<i>Children's right to education</i>	2.8	<i>Not relevant for stakeholders</i>
	<i>Children's right to healthcare</i>	2.9	<i>Not relevant for stakeholders</i>
	Marketing aimed at children	3.2	

¹The subcategories 'safe and healthy living conditions' and 'secure living conditions' are merged²Renamed from 'ethical treatment of animals'³Renamed from 'wealth distribution'

activity units, such as worker-hours required for producing the reference flow in each unit process. The selected activity variable is scaled to the functional unit of the study, thus allowing for the scaling of results. When worker-hours are

used as activity variable, the premise is that with a larger number of worker hours for a particular unit process, there is more time during which stakeholders, particularly workers,

may be exposed to (potential) social impacts within this unit process.

In this study, it has therefore been chosen to use worker-hours as activity variable for the stakeholder group *workers*. For *workers*, the worker-hours per kg of feed or livestock product were multiplied with the reference flow, i.e. the quantity of materials needed to produce the product or output for the functional unit. Worker-hours are directly linked to the use of time in each process step and therefore also to the risk of violations of workers' conditions and rights. The worker-hours for the functional unit, i.e. domestic-produced animal protein per capita, are shown in Table 4.

For the other stakeholder groups, it was not as obvious to use worker-hours based on the stakeholder group *workers'* working time. Yet, use of an activity variable was essential for distribution of the share of the various life cycle steps to be able to make quantitative assessments of the current production. Worker-hours for *workers* were still the most relevant activity variable to use for the stakeholder groups *local community* and *society* as it provides a relative distribution between the time for exposure to social conditions in the various communities and societies, e.g. in the country from which feed ingredients are imported.

Data for worker-hours for the different types of livestock productions and domestic crop production were calculated based on account statistics in agriculture and other references for mapping worker-hours (Hovland 2022; NIBIO 2020). There was no corresponding data for foreign crop production and therefore it was assumed the same number of worker-hours applied under Norwegian conditions but adapted by considering the difference in yield per hectare of different countries and crops.

Worker-hours were not appropriate for the subcategory 'animal welfare' in the stakeholder group *society*, as it does

not consider the animals' time. Instead, the distribution of protein production was used (Table 1), as it reflects the share of each animal species. The stakeholder groups *value chain actors*, *consumers* and *children* were restricted to only apply to domestic conditions. Only country or sector specific data was available so there was therefore no need to use an activity variable.

2.6 Impact assessment

2.6.1 Indicators and inventory

The indicators were developed using the UNEP methodological sheets (UNEP 2021) as a starting point and are described in detail in Supplementary material B. For some of the subcategories, it was challenging to establish applicable indicators and associated data. This particularly applies to some of the subcategories recently introduced in the revised S-LCA guidelines (e.g. employment relationship, sexual harassment, smallholders including farmers, wealth distribution, ethical treatment of animals, poverty alleviation, children concerns regarding marketing practices) which have not yet been used in S-LCA studies.

The study was based on generic data; inventory was collected from international databases, national statistics, indices, surveys, information from websites for the relevant stakeholders, and calculated data. Data is then contextualised to this case study through the scoring system and use of activity variables. For the 26 included subcategories, a total of 45 indicators have been established. Many of the subcategories thus have several indicators. This has been chosen to make the analysis more robust by having a broad data basis from many different sources. Table S1 and Supplementary material B provide a description of subcategories, indicators, inventory, and scores for each indicator.

2.6.2 Reference scale

The reference scale approach also known as Type I (UNEP 2020) was used. This approach estimates the likely magnitude and significance of potential social impacts based on available information. The data was assessed against a reference scale that was divided into four levels, ranging from score 1, for a low social performance, to score 4, for a high performance; see Table 5. A low social performance was defined as below score 3, i.e. below the median or acceptable threshold level. A reference scale was developed for each indicator based on global, European, or Norwegian norms or indices, depending on the context in which it was used in this study. When relevant statistics were available, threshold values were set, using the upper quartile, median, and lower quartile. Other scoring principles included converting existing scales from the original source and using colour codes in

Table 4 Reference flow given as worker-hours for domestically produced animal protein per capita for the current production distributed on the life cycle steps

Life cycle steps	Worker-hours per functional unit	Distribution between the life cycle stages (%)
Off-farm feed	0.91	10%
Dairy cattle	5.48	59%
Suckler cow	1.47	16%
Pig	0.63	7%
Chicken	0.15	2%
Egg	0.18	2%
Imported feed, Brazil	0.15	2%
Imported feed, Canada	0.04	0%
Imported feed, Latvia	0.20	2%
Imported feed, Poland	0.06	1%
Total	9.24	100%

Table 5 Description of the social performance four-point scale for the life cycle steps and belonging indicators

Score of life cycle steps	Score for indicator		Social performance	Assigning criteria
4	$x=4$		High	• Above the reference value • Equal to or above the upper¹ quartile • Ideal performance • High performance based on existing scales from the original data source
3	$3 \leq x < 4$		Acceptable	• Acceptable threshold level compared to the reference value • Between the median and the upper¹ quartile • Compliant performance • Medium performance based on existing scales from the original data source
2	$2 \leq x < 3$		Low	• Below the reference value • Between the median and the lower¹ quartile • Low performance • Low performance based on existing scales from the original data source
1	$1 \leq x < 2$		Very low	• Below the lower¹ quartile • Non-compliant, risky performance • Very low performance based on existing scales from the original data source
-	-		No data	• Data not available

¹What is referred to here as the upper quartile is the quartile that provides the most desirable performance. For some indicators, a low value gives the highest performance, e.g. Global Slavery Index. For such an indicator, the lowest quartile will be referred to as 'upper' and vice versa based on the rating criteria

indices. Where clear norms were not identifiable, threshold values for differentiating between performance levels were based either on ideal performance or incidence rate, from undesirable to desirable outcomes, as suggested by Pelletier (2018).

The impact assessment involved several levels of aggregation. For each life cycle step, data was collected for individual indicators, and a score was assigned according to the specified reference scale. Subsequently, the total score for each indicator across all life cycle steps was computed using activity variables (see Sect. 2.5). When aggregating to overall indicator level, the scores become decimal numbers and the scale is therefore given as colour-coded intervals; see Table 5. For subcategories with more than one indicator, an arithmetic average of their score across all life cycle steps was calculated for the overall score unless otherwise stated.

As an example, the scoring system for 'child labour' was applied using the SDG indicator percentage of population aged 5–14 involved in child labour, as detailed in the SDG report (Sachs et al. n.d.). The scale for this indicator was defined as score 4: $x=0$ (long-term objective), score 3: $0 < x \leq 2$ (green threshold), score 2: $2 < x \leq 10$, and score 1: $x > 10$ (red threshold). The life cycle step for imported feed from Brazil achieved score 2; the other life cycle steps achieved score 4. These subscores were weighted based on the distribution of worker-hours, which in this case was 2% for Brazil. Consequently, this life cycle step had a minimal impact on the overall score.

2.6.3 Scenario assessment

The social performance of the scenarios was assessed by the authors using the Delphi approach. The Delphi method is a systematic method of involving experts in problem analysis converting different viewpoints into one common conception through an iterative feedback process and is used in many different contexts, including sustainability assessment (Allen et al. 2019; Sackman 1974). The authors represent different disciplines and thus constituted an interdisciplinary group for expert evaluation. The scenario assessment was carried out by the authors writing short notes to describe whether a reduction, increase or unchanged social performance was expected for each subcategory. The notes were compiled and discussed together to achieve consensus. Since there was no existing inventory for the scenario subcategories, scores were not assigned; instead, the evaluation focused solely on predicting anticipated changes. These changes were categorised using a 5-point scale (slightly higher score, higher score, unchanged, slightly lower score, lower score).

3 Results

3.1 Current production

The current production was assessed for 25 subcategories and 45 associated indicators, and the results are shown in

Table 6. One subcategory was not assessed because data was not available. The results for the subcategories showed that 8 had a low or very low social performance, i.e. below the median or the threshold level. The subcategories with low scores belonged to all stakeholder groups except for *consumers* and *children*. The results at indicator level showed more variation, as they evaluate different social aspects, and by aggregating to subcategory level, important aspects can be lost. Therefore, indicators that have a very low score are included in the following description of results.

The results for *workers* were characterised by most of the working hours taking place domestically, and therefore, it was domestic conditions that dominated the results. The subcategories ‘fair salary’, ‘equal opportunities’, and ‘health and safety’ had a score below 3 and thus a high social risk for *workers*.

The indicator for ‘fair salary’ showed that the average monthly earnings in agriculture are lower compared to the average earnings of all sectors, especially for Norway, Brazil, and Canada. In Norway and several other countries, agriculture’s earning potential differs from other occupations as the income to a certain degree is governed by subsidies and other political instruments. When the average monthly income in agriculture is lower compared to the average income in all sectors, it becomes part of public responsibility. The indicators used for ‘equal opportunities’ concerned women’s salary level and ownership, and the results revealed great inequality. The share of female farmers is very low due to traditions and because it has previously been, and to some extent still is, physically demanding work. For women, it can therefore be challenging to become a farmer. This also applies to people with no connection to Norwegian agriculture since agriculture is largely run as family farms and recruitment often takes place within the family. A large share of traded farms is transferred to families and only about a third are sold in the open market (Statistics Norway 2019). This means that it is difficult to become a farm owner without a family link to agriculture. An additional challenge is the need for capital for farm purchases and investments.

For the subcategory ‘health and safety’, the indicators were based on domestic statistics for occupational accidents, sickness absence and mental health in agriculture, using all industries as a reference. The reported occupational accidents in agriculture had a very low score when compared to other sectors; however, the score for sickness rate was not correspondingly low. Human mistakes are often stated as the cause of accidents, and the accidents often occur in connection with handling livestock and using machines and tractors (Logstein et al. 2023). Although the sickness absence rate scored quite well, there may be more instances of sickness than the results

show. Surveys show that some farmers work even when they are sick because it can be difficult to get farmer substitutes during a period of sickness absence, in addition to likely financial consequences (Logstein et al. 2023). Mental health was also assessed as having a very low performance, using results from one region for men and women, respectively; however, similar results have been found in other regions (Riise et al. 2003). Self-assessment was another indicator that was used for assessing mental problems from a nationwide survey with many respondents (Logstein et al. 2023), which had a better score, but lacked comparable surveys from other professions. Still, accidents can lead to a poorer economy for farmers, which in turn can lead to psychological burdens such as uncertainty, stress, and mental illness (Hildrum 2021; Zahl-Thanem and Melås, 2022). Furthermore, a higher psychological morbidity amongst farmer families was indicated by Hounsome et al. (2012). Also, low occupational well-being and high levels of stress are associated with low animal welfare (Hansen and Østerås, 2019).

The remaining subcategories for *workers* were ‘freedom of association and collective bargaining’, ‘child labour’, ‘working hours in accordance with current regulations’, ‘forced labour’, ‘sexual harassment’, and ‘conditions for farmers/small businesses’, which all achieved a score above 3, i.e. high social performance. Two of these categories, i.e. ‘freedom of association and collective bargaining’ and ‘child labour’, demonstrated a low performance in some of the countries in the life cycle step of imported feed. The remaining subcategories had only minor differences between the countries. ‘Sexual harassment’ was only assessed for domestic conditions due to a lack of data from other countries.

For the stakeholder group *local community*, the subcategory ‘cultural heritage’ had a very low score. ‘Cultural heritage’ was assessed for domestic conditions by using the annual sum of subsidies for measures that promote the natural and cultural values in the agricultural landscape, which may include protection of endangered plants and facilitating grazing to prevent overgrowth. Since this indicator was based on subsidies, it has been identified that political priorities will be needed to improve this score. The other two subcategories ‘safe and secure living conditions’ and ‘local employment’ showed a score above 3. ‘Safe and secure living conditions’ includes protection of public health and safety in surrounding communities. The subcategory was assessed by three indicators. Pesticide use per hectare was used as indicator, as suggested by Zira et al. (2020), owing to the fact that a large amount of pesticide can lead to an increased risk of exposure in the immediate area, in addition to how pesticide residues can be found in locally produced foods. The pesticide use per hectare was low for Norway, but higher for some of the countries from which feed was imported, in particular for Brazil. The other two indicators

Table 6 Result for social performance for current production, shown at indicator level and subcategory level, using a four-point scale from 1 (low performance) to 4 (high performance or ideal value). The expected future changes in performance, compared to current produc-

tion, in the scenarios TrendProd and ChangeProd, are indicated with arrows: ↑ (slightly higher), ↑↑ (higher), → (unchanged), ↓ (slightly lower), ↓↓ (lower)

Stakeholder	Social subcategory	Indicators	Current production		Trend Prod	Change Prod
Workers	Freedom of association and collective bargaining	Collective bargaining coverage rate	2.96	3.43	↑	↑↑
		Trade union density rate	2.91			
		SDG 8 Fundamental labour rights are effectively guaranteed	3.93			
		ITUC Global Rights Index	3.91			
	Child labour	SDG: Percentage of population aged 5-14 involved in child labour	3.97	3.97	↑	↑↑
	Fair salary	Monthly earnings by agriculture compared to earnings from other economic activities	2.99	2.99	→	→
	Working hours	Share of employed working 49 or more hours per week	3.97	3.97	→	→
	Forced labour	Global Slavery Index	3.97	3.97	→	→
	Equal opportunities	Female monthly earnings by agriculture compared to earnings from agriculture	3.93	2.47	↑	↑↑
		Share of female farmers (%)	1.00			
	Health and safety	Reported occupational accidents in agriculture per 1,000 employees	1.00	1.75	↑	↑↑
		Sickness absence	3.00			
		Hospital Anxiety and Depression Scale, depression subscale; women	2.00			
		Hospital Anxiety and Depression Scale, depression subscale; men	1.00			
Local community	Employment relationship	No indicator	no data	no data	-	-
	Sexual harassment	Sexual harassment in agriculture, forestry and fishing, women	3.00	3.00	↑	↑
		Sexual harassment in agriculture, forestry and fishing, men	3.00			
		Access to agricultural input	3.02			
	Conditions for smallholders including farmers	Access to agricultural input	3.02	3.02	↓↓	→
	Cultural heritage	Subsidies for measures that promote the natural and cultural values in the agricultural landscape	2.00	2.00	↓	→
	Safe and secure living conditions	Pesticide use per hectare of cropland	2.96	3.32	→	↑
		Disaster risk management	3.00			
		Food safety	3.99			
	Local employment	Local supplier quantity	3.00	3.49	↓	→
		Local supplier quality	3.98			
Society	Public commitments to sustainability issues	Sustainability and Adaptation (country level)	3.89	3.89	↑	↑↑
	Corruption	Corruption Perceptions Index (country level)	3.94	3.94	↑	↑↑
	Animal welfare	Dairy cattle and suckler cow, share on pasture	4.00	2.79	↑	↑
		Dairy cattle, share of loose housing	2.00			
		Dairy cattle: calf housing (live weight of less than 150 kg)	2.00			
		Beef cattle: no data for indicator	-			
		Pigs: Stocking density	3.00			
		Chicken: Stocking density	3.00			
		Egg-laying hens: stocking density	3.00			
	Poverty alleviation	Poverty headcount ratio at \$3.20/day (%)	3.97	3.97	↑	↑
	Food security	Food Security overall score	3.89	2.96	↑	↑↑
		Self-sufficiency ratio	2.03			
	Fair competition	HHI-Index (concentration in a market)	2.00	2.00	↓	→
Value chain actors	Promoting social responsibility	Property rights	2.00	2.50	↑	↑↑
	Supplier relationship	Share of companies that reports on social responsibility	3.00			
	Distribution of income between suppliers and retail	The collaboration between retailer and supplier	3.50	3.50	→	↑
	Health and safety	Ratio of change in the producer price index compared to the change in consumer price index	3.00	3.00	→	↑
Consumers	Transparency about working conditions and sustainability	Antimicrobial agents for food-producing livestock	4.00	4.00	→	↑
	End-of-life responsibility	Sustainable Brand Index production	3.33	3.33	↑	↑
Children	Children concerns regarding marketing practices	Information on packaging for selected animal products	3.00	3.00	↑	↑
		Proportion of food and drink advertisements that cannot be marketed to children	3.00	3.00	↑	↑

were ‘disaster risk management’ and ‘food safety’ from the Global Food Security Index. Both had a high performance for all the countries involved in the food supply chain. ‘Local employment’ was assessed by local supplier quantity and quality from the Global Competitiveness Report (Schwab 2017). These indicators had a high performance, except for local supplier quantity for Latvia.

The subcategories ‘animal welfare’ and ‘food security’ had a low social performance for the stakeholder group *society*. The subcategory ‘animal welfare’ was rephrased from ‘ethical treatment of animals’ which is one of the new subcategories in the guidelines (UNEP 2020, 2021). Several different indicators were considered, e.g. based on legislation, market initiatives (Sandøe et al. 2022), and

measuring actual welfare through observations. Legislation and regulations are important for assessing animal welfare at an overall national level, but there is still no guarantee that these are followed. Market initiatives will often have stricter requirements than the regulation and are aimed at specific production systems and products. Mortality rates for each animal species were considered as relevant indicators, but there were no statistical data for European countries available for preparing a reference scale. Therefore, ‘animal welfare’ was assessed by required stocking density for the different animal species. For dairy cows, however, there was no provision for stocking density and therefore the share of dairy cows on pasture (van den Pol-van Dasselaar et al. 2020) and loose housing was used, based on EFSA welfare of dairy cows (2023). The indicators for the share of loose housing for dairy cattle and the space allowance for calves had very low score. The space allowance for calves in Norway was the same as in the EU, but for monogastric animals the space requirement is stricter in the Norwegian regulations than in the EU’s Council directives (EU 2019). For dairy cows, there are no EU regulations or prohibitions to zero-grazing systems. In Norway, however, cattle must be ensured the opportunity for free movement and exercise on pasture for a minimum of 8 weeks during the summer. Although there are no regulations on grazing, it is still a widespread practice in some countries, such as Ireland, the UK and Switzerland. In conclusion, there was a lower share of loose housing for dairy cows in Norway compared to other countries, approximately two-thirds of the cows were in loose housing systems, but from 2034, this will become a requirement in Norway.

The subcategory ‘food security’ was measured by the Global Food Security Index (Economist Impact 2022) and the self-sufficiency ratio. The two indicators used for this subcategory gave quite different results. The Global Food Security Index covers several topics such as food affordability, availability, quality and safety, sustainability and adaptation, and the scores were high both for Norway and the countries from which feed is imported. The self-sufficiency ratio is computed as the ratio of domestic production to domestic consumption, which takes into account imports and exports (FAO and Clapp, 2015). Norway had the lowest self-sufficiency ratio, but also Brazil and Poland had a low ratio according to Puma et al. (2015).

For the stakeholder group *value chain actors*, the subcategories ‘fair competition’ and ‘promoting social responsibility’ exhibited a low social performance. The subcategory ‘fair competition’ was limited to wholesale and retail. The subcategory was assessed by using the market concentration quantified by the Herfindahl–Hirschman Index (Rhoades 1993), where low values indicate that the market is not concentrated, and the highest value indicates that one part has 100% market share. The subcategory showed a very low

score due to a high Herfindahl–Hirschman Index which indicated a high market concentration in the wholesale and retail market in Norway (Norwegian Ministry of Trade 2020). A high market concentration hinders the entry for new actors to establish themselves in the market and, together with other factors such as scattered population and the agricultural policy, can lead to higher prices and a smaller selection of products. The retail sector is dominated by a few players, with several of the suppliers having strong market power. Increased competition in retail is therefore desirable because it increases the opportunities for farmers to sell their products at acceptable prices and the market will be more efficient.

For the subcategory ‘promoting social responsibility’, the hotspot analysis showed a low performance of exceeding property rights in Brazil, and this was confirmed by information from the Business and Human Rights Resource Centre (2021). A very low score was therefore given for this indicator.

The subcategory ‘distribution of income suppliers and grocery market’ was measured by the ratio between the change in the producer price index compared to the change in the consumer price index. An imbalance in price development was identified, as the producer price index increased much more (7.3% per year) (Statistics Norway 2023b) than the consumer price index (2.2% per year; Statistics Norway 2023a) in the same period. This is however a positive development, as the income gap for farmers is reduced.

The subcategories for the stakeholder groups *consumers* and *children* all demonstrated high social performance. ‘Health and safety’ for *consumers* can be assessed in many ways; in this study, it was necessary to relate the indicator to livestock products and thus the use of antimicrobial agents for food-producing livestock was applied. The indicator achieved a high performance due to a very restricted use in Norway. High levels of antibiotic use in farming are associated with increased antibiotic resistance, which is a threat to both human and animal health (Nunan 2022). Antibiotics have been used routinely to compensate for inadequate husbandry or poor hygiene and thereby pose a risk of increased antimicrobial resistance; however, this is now prohibited in the EU (Nunan 2022; Schmerold et al. 2023). One of the reasons why Norway has achieved a low antibiotic routine use is because of the generally higher requirements for animal welfare. Efficiency requirements and demands for affordable meat and dairy products can lead to a lower priority of animal welfare, and this is one of the main reasons why so many countries had excessive use of farm antibiotics and significant animal health problems before the ban was introduced (Nunan 2022). As the ban came into force after the current production year 2019, it was still relevant to use this indicator for consumers’ ‘health and safety’.

For ‘transparency about working conditions and sustainability’, all the meat and dairy manufacturing represented in the Sustainable Brand Index had a ranking amongst the 50 best out of a total of 247 companies (SB Insight 2020). This shows that consumers have great confidence in these food companies and their environmental and social responsibility.

The subcategory ‘children concerns regarding marketing practices’ was assessed based on the proportion of food advertisements promoting unhealthy food. Children are a vulnerable group which must be protected against marketing particularly aimed at them. In Norway, the marketing of unhealthy food and drink to children and young people is restricted through a self-regulated, industry-led committee (Matbransjens Faglige Utvalg, n.d.). Therefore, according to good and responsible marketing practices, it is not acceptable to market unhealthy foods directed towards children. Systematic mapping of this has been carried out (Bugge and Rosenberg 2016), showing that 3% of all advertisements and 16% of food and drink advertisements directed at children involved unhealthy products. The findings indicate that the extent of unhealthy food and drink advertising towards children is quite limited.

3.2 Scenarios

The future scenarios of TrendProd and ChangeProd were qualitatively assessed by comparing the expected changes to current production with the outcome presented in Table 6 and detailed descriptions in Table S3 in Supplementary material A. Most of the subcategories are expected to have unchanged or higher performance in the scenarios, as competence and technology improves.

For the TrendProd scenario, a lower performance was assumed for the *workers* subcategory ‘conditions for smallholders including farmers’ due to larger farms, because feed could become more expensive and give increased pressure on land area due to climate changes. This could lead to higher efficiency demands, which in turn might increase pressure on farmers’ mental health. Despite mental health problems, it was assumed that the accident rate would be significantly reduced, due to technology that improves working conditions, and thus, the overall performance for this subcategory was expected to improve. A low performance for *local community* subcategory ‘cultural heritage’ was assumed because of increased focus on production efficiency and the UN biodiversity agreement (United Nations 2022a). The biodiversity agreement is supposed to strengthen the protection of land areas but can also set limitations for agriculture. The cultural landscape can disappear if it is not actively used for, e.g. grazing animals. ‘Local employment’ was also at risk of being reduced as more technical and less labour-intensive work can result in fewer jobs. On the other hand, there could be

more jobs in feed production to replace imported feed, but the effect of this could be limited. For *value chain actors*, the subcategory ‘fair competition’ which already had a high risk in current production could be weakened further due to structural changes towards more concentrated farming in productive areas. This could lead to a higher market concentration in wholesale and retail and a greater share of private labels that control the entire value chain. ChangeProd was expected to have a higher social performance compared to TrendProd. The subcategory ‘conditions for smallholders including farmers’ would be affected both positively and negatively in ChangeProd because the utilisation of new feed ingredients could require additional work due to the implementation of new systems, which can offset the effect of lower livestock production. The use of new feed ingredients might also increase the risk of disease transmission and could change consumers’ perception and acceptance of the livestock products. How it would affect animal welfare is unknown, but it was assumed that livestock was fed in such a way that it would not have negative impacts on the animals. The subcategory ‘cultural heritage’ was unchanged, as the cultural landscape would have a high value and grass areas would be largely used, but as mentioned above, the biodiversity agreement could also set limitations for the use of land areas. ‘Local employment’ was expected to maintain high performance due to the demand for both technical and labour-intensive work; however, it might be difficult to find sufficient workforce in rural areas. For the subcategory ‘fair competition’, no changes were assumed.

The scenarios also involved several positive changes, in particular ‘health and safety’ for *workers* and ‘animal welfare’ which had a low performance in the current production. For TrendProd, the high domestic risk for occupational accidents would be reduced due to more milking robots (Karttunen et al. 2016) and technology that improves working conditions, e.g. better indoor climate in poultry production. In the ChangeProd, the performance would be further improved by eliminating the production of chicken and beef cattle, as these productions have a high risk of lung disease linked to dust and accidents when handling animals (Sigsgaard et al. 2020; Viegas et al. 2013). Both scenarios would improve the performance for ‘animal welfare’ due to better protection and more knowledge about animals’ need for natural behaviour and improved regulations that also affects the actual conditions.

A large part of the subcategories that are linked to human rights had a low score for countries from which the feed is imported. In ChangeProd, it was assumed that all feed should be sourced domestically, and feed for livestock production should be based on using domestic resources and residual products that are not suitable for human consumption. When feed is no longer imported, the social performance

will therefore be increased. This does not imply that the social issues would disappear in these countries, but rather that they would no longer be directly linked to the supply chain for Norwegian livestock production. If import from countries with human rights problems is reduced or ceases, this should occur gradually and be followed up with action to improve conditions for those affected. In TrendProd, where feed imports still occur, it is important to request certified products and promote fair trade agreements.

In the ChangeProd, the animal protein production was reduced, and it was assumed to be covered by domestic grain and vegetable production, but it could also be completely or partially replaced by fish or imported vegetables. The social performance associated with the production of these was not included in this study, which was limited to livestock production. According to Mancini et al. (2023), the social risk was higher for fruits and vegetables than for animal-based products, indicating that trade-offs might occur in the design of sustainable diets containing less animal-based products. This finding is also confirmed by Frehner et al. (2021) who assessed future dietary scenarios and found trade-offs between environmental and social impacts.

4 Discussion

The results are thoroughly explained in the previous chapter and therefore this discussion chapter has more focus on application and methodological implications in this study. The analysis shows that there is a high social performance for most of the subcategories and this applies especially to domestic conditions. Because activity variables for *workers, local community and society* (except animal welfare) have been used to measure the relative share of the life cycle steps, the results for imported feed have little effect on the final score for each subcategory. This largely also reflects the actual mass flow for domestic livestock production, as most of the activity takes place domestically. An alternative to use worker-hours could be to use economic added value to provide information about the importance of social issues for the unit processes in a system. However, the use of added value as activity variable can give the wrong indication as high added value of unit processes is not only due to many worker-hours but can also be due to high labour costs, a high degree of technology or a low number of worker-hours (UNEP 2020). The use of activity variables could be debated because the potential social impacts do not depend on the physical flows or working hours, but instead more on the behaviour of the companies and stakeholders involved. Other previous S-LCA studies have only to a small extent linked results to the functional unit (Tragnone et al. 2022; Zanchi et al. 2018), which has significance when interpreting the results (Pollok et al. 2021). When an activity variable is

used in the calculation of the results, this reflects the actual distribution and is more consistent with the method of environmental LCA.

The subcategories included in this study were selected using a participatory approach as suggested by the S-LCA guidelines (UNEP 2020) as well as a hotspot analysis using databases as applied in other case studies (Du et al. 2019; Ekener-Petersen et al. 2014; Mancini et al. 2023; UNEP 2020). This approach led to the inclusion of many subcategories with associated indicators, which provided a broad assessment. However, this also increased the need for focusing on and prioritising the most important impacts to draw conclusions (Zanchi et al. 2018). Alternatively, the results can be aggregated or weighted, but it is vital that this does not take place at the expense of transparency. Also, the question arises whether each individual indicator should count equally or whether different weights should be used. According to the S-LCA guidelines (UNEP 2020) the absence of weighting or the use of weights with the same value can give a false sense of neutrality due to it being assumed that all indicators have equal relevance. Still, equal weighting can be applied when indicators are deemed as robust and as relevant as one another. In this study, a thorough assessment was made of the indicators that were applied, and if an indicator was found imprecise or unimportant, it was excluded. When subcategories were composed of more than one indicator, an average of the scores was calculated using equal weights, with some exceptions. This applies, for example, to health and safety, where sickness absence and mental health make up one part and occupational accidents the other. For animal welfare, the individual indicators are weighted according to the distribution of produced protein in the reference flow.

Quantitative data has been largely used in this study, both as inventory for each life cycle step and in developing the reference scale. For some of the indicators, dataset was used to calculate quartiles as threshold values. Qualitative data has also been used, e.g. for ‘animal welfare’ and for ‘promoting social responsibility’. The challenges associated with using qualitative indicators include the need to quantitatively link the impact to the functional unit and to compile and aggregate both qualitative and quantitative results. Chen and Holden (2017) suggested dividing the indicators into different groups, i.e. functional unit-related quantitative indicators, non-functional unit-related quantitative indicators, and semi-quantitative indicators. In this study, the qualitative data was used to develop a scale that allows the results to be handled quantitatively. There are thus several usable ways of handling quantitative and qualitative data, and the choice should be based on the goal and scope for the study and the data access.

Whilst S-LCA offers valuable insights into the social aspects of products, it is important to acknowledge its limitations and uncertainties. These limitations can influence

the accuracy of the results and several factors contribute to these: activity variables, generic or specific data, development of reference scale, choice of indicators and aggregation of results.

The use of activity variables is discussed above and can significantly affect the outcomes of the study. The choice of these variables may vary depending on the context and goals of the study. S-LCA often relies on generic data due to the lack of specific information available for certain social aspects. Whilst generic data provides a basis for analysis, it may not accurately reflect the conditions of a particular product or service. Consequently, the findings of S-LCA may not fully capture the social impacts associated with a specific product system. Our choice of using generic rather than specific data might have affected the outcome of the study. For example, our approach using generic data would not capture if a company's specific data could demonstrate documented social corporate responsibility, potentially leading to a higher company performance compared to the national averages.

Establishing a reference scale is essential for comparing and interpreting the results of S-LCA but it can be difficult to determine the different levels of the scale. The choice of norm sets or indices is often determined by their availability. Although it could be desirable to develop a consistent reference scale for, e.g. a global level, reference data will not be available for all indicators. In this study, a mix of reference areas has been employed, i.e. global, European, or Norwegian norms or indices. This approach is justified by the specific context of the study. The selection of indicators is crucial as they serve as metrics for evaluating social impacts. The S-LCA guidelines provide methodological sheets (UNEP 2021) proposing different indicators for each subcategory that allow for varieties in interpretation when it comes to the choice of indicators and the associated data sources. When using participatory approach, different stakeholders may prioritise different subcategories and indicators. Therefore, it becomes difficult to compare results from different studies. Aggregating indicators into overall scores or indices can facilitate interpretation; however, it may oversimplify complex social issues and mask important nuances. Although there are many methodological limitations and implications, the S-LCA method provides a systematic way to assess a large amount of information and provide an overview of a wide range of social issues for the stakeholder groups.

5 Conclusion

The social life cycle assessment of Norwegian livestock production revealed an overall high social performance in the current production. The subcategories with a low performance, i.e. below the median or acceptable threshold level, were 'fair salary', 'equal opportunities' and 'health

and safety', mainly because of working conditions, efficiency requirements and traditions linked to family farms; 'cultural heritage' by cause of lower subsidies to promote the agricultural landscape; 'animal welfare' due to low share of loose housing for dairy cattle and small space allowance for calves; 'food security' because of the low self-sufficiency ratio in Norway; 'fair competition' because of high market concentration in the retail market; 'promoting social responsibility' due to high risk of exceeding property rights. Limitations and uncertainties of the study have also been identified, some related to data (generic or specific data, choice of indicators) and others to the application of method (activity variables, development of reference scale, aggregation of results).

The qualitative assessment of the scenarios indicated that most of the subcategories that were expected to remain unchanged or have better social performance were driven by assumptions of improved skills and technology. Overall, ChangeProd achieved a higher assumed social performance compared to TrendProd, because no feed would be imported, thus reducing the impact from the countries from which the feed would have been imported.

As the S-LCA methodology is still under development, this study shows the application of several of the newly introduced subcategories. A stakeholder survey was used for subcategory selection and 'food security' was proposed as a new subcategory, addressing societal concern for self-sufficiency and food security. Moreover, aggregation of results was applied through several steps to ensure transparency. Scenarios were included and evaluated using a Delphi approach due to insufficient data for a more quantitative assessment. Although not inherent to the S-LCA method, this approach to the inclusion of scenarios provides opportunities for further exploration.

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Data availability The data used in this study are fully available and reported in Supplementary materials A and B.

Declarations

Conflict of 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. The survey was carried out as part of the NewTools project involving stakeholders from across the Norwegian food system, including partners with financial and political interests. Research integrity is secured through a defined framework of collaboration.

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