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LCA FOR AGRICULTURAL PRACTICES AND BIOBASED INDUCTRIAL PRODUCTS

Social life cycle assessment of Swedish organic and conventional pork production

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Abstract

Purpose Sustainable animal food systems are increasingly important to society. Yet for pork, the most consumed meat product in Europe, there is no social life cycle assessment (S-LCA) in the literature. The breath and complexity of social issues and lack of data makes the task challenging. This study examines the risk of negative social impacts in Swedish pork production systems and includes *workers*, *farmers*, *consumers*, *local community*, *society*, and *pigs* as stakeholders.

Methods The objective was to assess the risk of negative social impacts for the production and consumption of 1000-kg pork (fork weight—bone free meat including cooking losses) originating from two different systems: organic and conventional pork production. Relevant social sustainability issues for pork production systems were identified through a literature search and a consultative workshop with experts. A life cycle inventory was conducted to collect data for activity variables and compute Social Risk (SR), a measure of the risk of negative social impacts related to a reference (here the average European social conditions). Analytical Hierarchical Process (AHP) was used to obtain weights for subcategories. The SR scores and the weights were used to calculate Social Risk Time (SRT) that relates the Social Risk to the functional unit by considering the 'exposure' to the risk, and the Social Hotspot Index (SHI), which relates the SRT to the worst possible situation for that system.

Results and discussion The conventional pork system had 42% of inventory indicators with SR > 0.5 and the organic pork system had 32%. For all stakeholders, the *pig farm* had the largest SRT in both production systems except for *workers* in the organic pork system where the s*oybean farm* had the largest SRT. In the conventional pork system, *society* as well as *farmers* at the *pig farm* had SHI > 0.5 slightly, meaning performing the same as European average. In the organic pork system, SHI < 0.5 for all stakeholders and subsystems.

Conclusion Swedish pork production has lower risk of negative social impacts than the average European social conditions for most of the stakeholders: *workers*, *pigs*, *local community*, and *consumers*. *Farmers* and *society* at the subsystem *pig farm* have the same risk of negative social impacts as the average European social conditions. Due to the dependence of the results of the chosen reference level, the reliance on certification, and the indicators included, results should be interpreted and used with care.

Keywords Social life cycle assessment · Pig · Activity variable · Social Hotspot Index · Social Risk Time · Analytical hierarchical processing

1 Introduction

Pork is the most consumed terrestrial animal meat product in Europe as well as globally. It accounts for 47% of the meat produced in Europe and pork production is growing fast; currently there is a stock of almost a billion pigs worldwide (FAOSTAT 2019). Producing pork requires various resources: the animals themselves, housing facilities, feed, farming machinery, trained farmers and animal caretakers, slaughter facilities, transportation networks, and energy. Several pork production systems (hereafter called pork systems) are operated in Europe. The most common involves rearing pigs indoors in conventional, confined environments (approximately 90% of the slaughter pigs), but there are also alternative

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outdoor or partially outdoor systems including organic pork systems (Bonneau et al. 2011). In Sweden, there are two main pork systems: conventional and organic, with around 2% of production being organic (Jordbruksverket 2017). Both systems use the same high-yielding crossbreds, and the main differences between the systems relate to feed and housing.

The environmental impacts of Swedish pork production, in terms of energy use and potential contribution to global warming, acidification, and/or eutrophication, have previously been examined (Sonesson et al. 2016; Cederberg et al. 2009; Carlsson et al. 2009; Sonesson et al. 2009; Cederberg et al. 2005; Eriksson et al. 2005; Cederberg and Nilsson 2004; Cederberg 2003; Ingvarsson 2002; Cederberg and Darelius 2001). Most studies have focused on environmental hotspot analyses, which indicate that the largest environmental impact comes from feed production and manure management (Sonesson et al. 2016; Cederberg et al. 2005; Eriksson et al. 2005; Cederberg 2003; Cederberg and Darelius 2001). Environmental impacts of organic and conventional pork in Sweden from farm to supermarket (Ingvarsson 2002) and from farm to fork (Carlsson et al. 2009; Sonesson et al. 2009) have also been studied, but the social impacts of different pork systems have not yet been researched.

Sustainable food production is increasingly important to society, practitioners, and academics, partly as a result of the Sustainable Development Goals (SDGs) from the United Nations (UN 2015). The SDGs describe development as a matter not only of economic growth but also of the provision of solutions to social sustainability issues such as poverty, hunger, poor health, low education, gender inequality, access to clean water, access to sanitation, limiting global warming, and other forms of social injustice (UN 2015). In addition, a growing segment of the population assesses product quality not just by intrinsic attributes but also by extrinsic attributes connected with sustainability (Jawad et al. 2018; Benoit-Norris et al. 2012). Although consumers of pork are concerned about direct personal benefits such as their health and safety, they are also concerned about the health and welfare of pigs (Grunert et al. 2018). Grunert et al. (2014) showed that consumers in northern Europe are more concerned about social than environmental and economic sustainability. Hence, there is a need for actors in the food value chain to address not only environmental aspects but also social sustainability. A useful methodology for assessing social impacts from a product perspective is Social Life Cycle Assessment (S-LCA). The S-LCA has been standardized in the guidelines for Social Life Cycle Assessment of a Product (UNEP 2009), henceforth referred to as the 'guidelines'. The guidelines conform to the ISO 14040 implementation steps: definition of goal and scope, life cycle inventory, life cycle impact assessment, and interpretation.

Previous S-LCA studies have focused on various agricultural products including bananas (Feschet et al. 2013), broilers (Tallentire et al. 2019), cane sugar (Nemarumane and Mbohwa 2015), citrus fruits (De Luca et al. 2015), eggs (Pelletier 2018), honey (D'Eusanio et al. 2018), milk (Chen and Holden 2017; Revéret et al. 2015), tomatoes (Petti et al. 2018; Bouzid and Padilla 2014; Andrews et al. 2009), and wine (Arcese et al. 2017). However, most of the studies to date only include *workers* and *local community* as stakeholder categories, few are quantitative (Traverso et al. 2018), and to our knowledge, no S-LCA study has been conducted for pork. Animal ethics is increasingly being regarded as an important aspect of social sustainability in life cycle assessment (Neugebauer et al. 2014). Nevertheless, only one S-LCA study has included animals as stakeholders (Tallentire et al. 2019). Two other S-LCA studies have included animal welfare aspects (Pelletier 2018; Revéret et al. 2015), but their focus was on animal caretakers, not the animals themselves. Animal caretakers and animals are both important stakeholders and need to be included in a sustainability assessment (Neugebauer et al. 2014).

The objective of the study is to assess the risk of negative social impacts in organic and conventional pork systems. This study contributes to the literature on the S-LCA for livestock systems in two respects: (i) by quantitatively focusing on pork originating from two production systems, (ii) by including several major relevant stakeholders: *workers*, *farmers*, *consumers*, *local community*, *society* as a whole, and *pigs*.

2 Materials and methods

Following the guidelines, our S-LCA was undertaken in four main steps: definition of goal and scope of the study (Section 2.1), life cycle inventory (Section 2.2), life cycle impact assessment (Section 2.3), and life cycle impact interpretation (Section 2.4), as shown in Fig. 1.

2.1 Definition of goal and scope of the study

2.1.1 Goal of the S-LCA

The goal was to assess risks of negative social impacts in organic and conventional production systems in Sweden, using high-performance crossbred animals in both systems. In this study, risks of *potential* social impacts were assessed and not *actual* social impacts, which requires case-specific and primary data for the systems under study and also an establishment of cause-effect relations between activities affected by the production and the outcomes in terms of impacts on human health and life expectancy etc. (Macombe et al. 2013). Results are presented using different levels of aggregation for each stakeholder and subsystem, i.e. life cycle step, separately in order to enable identifying hotspots in pork production.

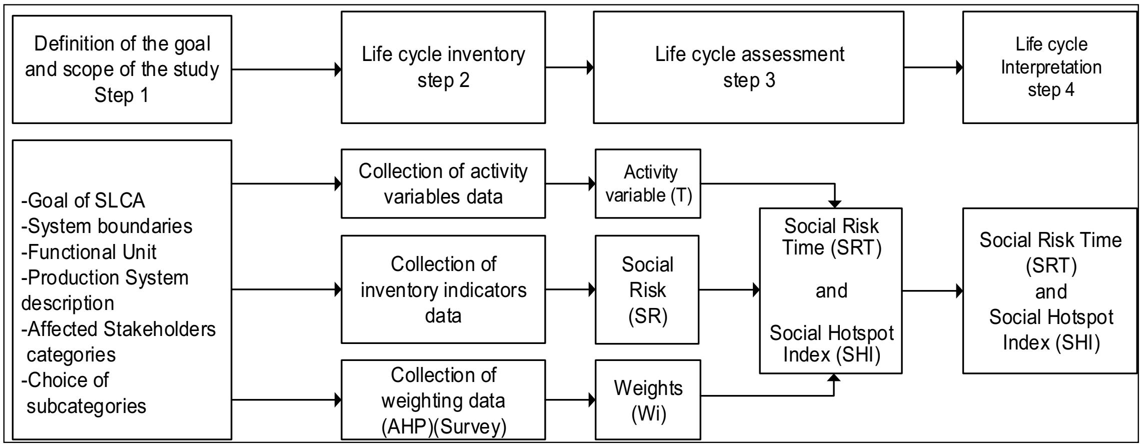

Fig. 1 The framework of the social life cycle assessment performed in this study showing the stages and the activities involved

2.1.2 Functional unit

The functional unit was 1000 kg of pork for consumption in Sweden (i.e. ‘on the fork’, excluding bones and not including waste at the consumer level). A pig slaughtered at 120-kg live weight results in 43-kg pork for consumption (Åsa Öberg Jordbruksverket personal communication 26 May 2020). All social risks were allocated to pork since pork is the main product from pig production.

2.1.3 System boundaries

The system boundaries are presented in Fig. 2. They include the following processes: on and off farm feed production, pig production, slaughter of pigs, and consumption of pork. The main feed crops used in Swedish pork production are wheat, barley, soybean, and rapeseed (LRF 2015). Swedish pork production uses local and imported protein sources, together with local cereal commonly produced at the pig farm. The feed requirements in the production of the functional unit are different for the two pork systems because organic pigs have higher maintenance energy requirements due to more space allowed for movements. *Pig production* refers to the rearing of parent stock (excluding grandparents) and rearing of young pigs for slaughter. *Slaughter* refers to the slaughtering of pigs and the cutting of the carcass into meat at a slaughterhouse for the market, and *consumption* is the eating of pork by consumers. The soybean farm, rapeseed farm, pig farm, slaughterhouse, and consumption are subsystems in the production systems. The cultivation of wheat and barley is accounted for in the pig farm subsystem because these are produced at the pig farm. Table 1 shows the stakeholders included for each subsystem.

To limit the scope of this study, that is, already comprehensive considering the multitude of stakeholders included, impacts related to the production of buildings, machinery, fertilizers, and transports, and energy use in retail and for cooking, feed processing, and minor nutrients in pig diets were not included. We assumed these processes have a lower relative importance owing to their low contribution to the functional unit, i.e. low values of the activity variables for these processes in the production of the functional unit 1000-kg pork (see Section 2.2.1).

2.1.4 Pig production system description

Typical conventional and organic pig farms were modelled for one production round (farrowing to finishing) based on Swedish data (Ingvar Eriksson Gård och Djurhälsan personal communication 16 August 2019; Agriwise 2018; Nils Lundeheim Swedish University of Agricultural Sciences (SLU) personal communication 12 November 2018; AHDB 2017; Gård och Djurhälsan 2017). We modeled farms with integrated pig production including sows, piglets, gilts, and slaughter pigs at the same farm. We excluded the boars as most farms use artificial insemination. The characteristics in Table 2 depict a typical farm of each production system.

2.1.5 Stakeholder categories

This study examines social risks on *workers*, *farmers*, *consumers*, *local community*, *society*, and *pigs* separately within the system boundary. *Workers*, *consumers*, *local community*, *value chain actors*, and *society* are stakeholders suggested by the guidelines. Considering that there are many small and large *value chain actors* and that data collection would be very challenging, we did not include *value chain actors*, such as manufacturers and retailers in order to limit our already broad scope. *Pigs* and *farmers* were added, as they are central stakeholders in pork production. We identified *workers* as those directly involved in work for a salary in crop production (used for feed), pig husbandry, and slaughter. We defined *farmers* as the owners of pig production enterprises in Sweden. *Farmers* and *workers* were treated as separate stakeholders in order to take into account that social sustainability issues important for *farmers* do not necessarily affect *workers*

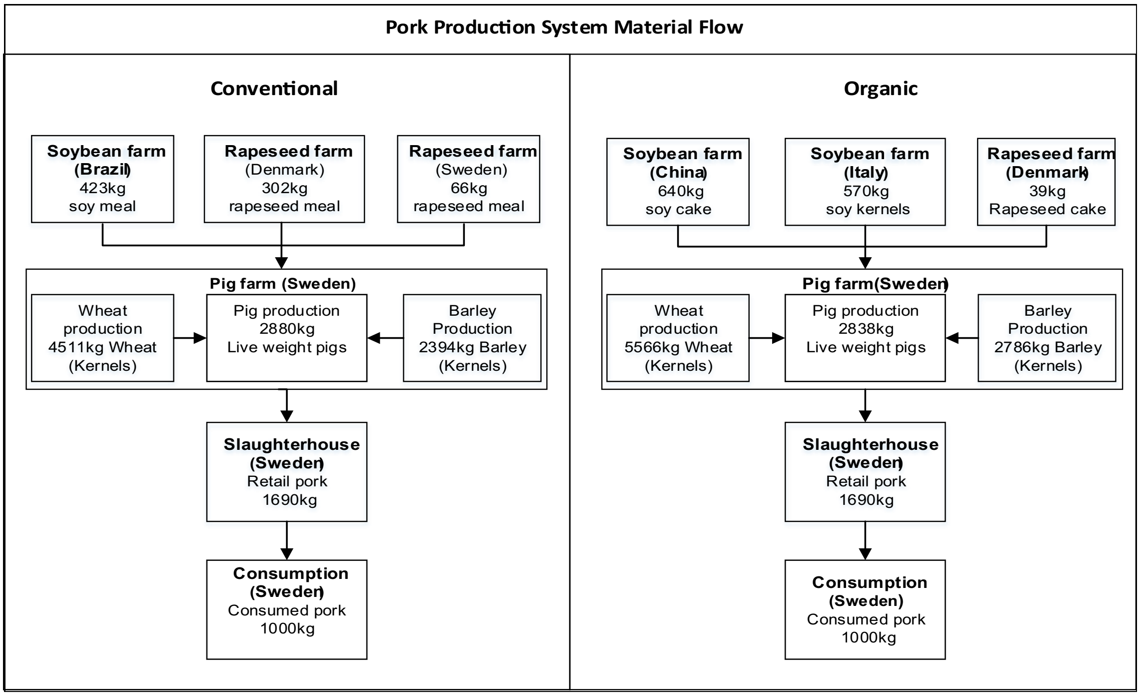

Fig. 2 System boundary and the production system material flow showing the inputs required per round of production of 1000 kg of pork for consumption (the functional unit) in terms of retail pork, live pigs, soybean, rapeseed, wheat, and barley (including co-products and waste)

at the *pig farm* and vice versa. *Local community* was, based on the study by Sarr et al. (2010), defined as residents living within 3 km^2 of the farms (soybean, rapeseed, and pig farms) and slaughterhouses. *Pigs* refers to sows, gilts, piglets, and growing pigs. Boars were not included, as their impact, with the low amount of semen required to produce the functional unit, can be considered marginal. *Consumers* were defined as people who eat pork in Sweden. Finally, based on a study on rural commuting in the UK (Champion et al. 2009) and assuming that people living within a radius of 25 km would reflect society, *society* was defined as people living within an area of 2000 km^2 around the farms. Table 1 shows the stakeholders and subsystems included.

2.1.6 Choice of subcategories

This is, to our knowledge, the first S-LCA study on pork, so it was necessary to identify subcategories of potential relevance to

Table 1 Included stakeholders and subsystems

Subsystem	Stakeholders					
	Workers	Farmers	Local community	Pigs	Consumers	Society
Soybean farm	X	-	X	-	-	X
Non-GMO conventional soy—Brazil; organic soy—China and Italy						
Rapeseed farm	X	-	X	-	-	X
Conventional rapeseed—Denmark and Sweden; organic rapeseed—Denmark						
Pig farm	X	X	X	X	-	X
Rearing pigs, and cereal production included—Sweden						
Slaughterhouse, Sweden	X	-	X	X	-	-
Consumption, Sweden	-	-	-	-	X	-

The stakeholder categories analyzed are annotated with an (X) while those with a (-) were either not applicable (e.g. pigs at soybean farm) or not included for the purpose of simplifying the model (soybean farmers and rapeseed farmers) or not included because no social sustainability issues were raised (slaughterhouse in society)

Table 2 Characteristics of conventional and organic pig production in Sweden

	Conventional	Organic	Source
Sow			
Number of litters/sow per year	2.3	2.1	(Nils Lundeheim SLU personal communication 12 November 2018; AHDB 2017)
Live born piglets per littre	14.6	12.4	(Gård och Djurhälsan 2017; Agriwise 2018)
Mean daily weight gain pre weaning nursery (kg/day)	0.3	0.3	(Nils Lundeheim SLU personal communication 12 November 2018)
Weaning age (days)	33	42	(Ingvar Eriksson Gård och Djurhälsan personal communication 16 August 2019; AHDB 2017)
Mortality piglets nursery (% of total of live born pigs)	18	21	(Gård och Djurhälsan 2017)
Piglets live weight at weaning (kg)	10	13	(Nils Lundeheim SLU personal communication 12 November 2018; AHDB 2017)
Mortality sows (%)	7	7	(Ingvar Eriksson Gård och Djurhälsan personal communication 16 August 2019)
Culled sows in % of total number of annual sows	50	40	(Nils Lundeheim SLU personal communication 12 November 2018)
Gilt age at first farrowing (days)	354	367	(Nils Lundeheim SLU personal communication 12 November 2018)
Gilt weight at first insemination (kg)	140	140	(Nils Lundeheim SLU personal communication 12 November 2018)
Mean sow weight (kg)	240	240	(Nils Lundeheim SLU personal communication 12 November 2018)
Growing and finishing pig			
Mean daily weight gain 11–35-kg weaners (kg/day)	0.6	0.57	(Ingvar Eriksson Gård och Djurhälsan personal communication 16 August 2019)
Post weaning nursing period (days)	42	38.5	(Nils Lundeheim SLU personal communication 12 November 2018)
Mean daily weight gain 36–60-kg growers (kg/day)	0.68	0.65	(Nils Lundeheim SLU personal communication 12 November 2018)
Growing period (days)	37	38	(Nils Lundeheim SLU personal communication 12 November 2018)
Mean daily weight gain 61–110-kg finishers (kg/day)	0.9	0.85	(Nils Lundeheim SLU personal communication 12 November 2018)
Finishing period (days)	67	68	(Nils Lundeheim SLU personal communication 12 November 2018)
Mortality weaners (% of total number of weaners)	2	4	(Ingvar Eriksson Gård och Djurhälsan personal communication 16 August 2019)
Mortality growing pigs (% of total number of growers)	1	1.9	(Ingvar Eriksson Gård och Djurhälsan personal communication 16 August 2019)
Mortality finishers (% of total number of finishers)	1.8	1.6	(Ingvar Eriksson Gård och Djurhälsan personal communication 16 August 2019; Nils Lundeheim SLU personal communication 12 November 2018; Agriwise 2018)
Live weight at slaughter (kg)	124	120	(Nils Lundeheim SLU personal communication 12 November 2018; Ingvar Eriksson Gård och Djurhälsan personal communication 16 August 2019)

pork. We adopted a bottom-up approach as suggested by the guidelines in which we first identified the major social sustainability issues associated with pork based on a literature search and an expert workshop, and then classified the identified social sustainability issues found into subcategories suggested in the guidelines and additional ones applicable to the social sustainability issue in question. To gather social sustainability issues, we selected articles from peer-reviewed journals and publications from international non-governmental organizations (NGOs) using Google Scholar. Web of Science and Scopus databases were checked for potential additional issues but no issues not already captured by the search using the Google Scholar were found.

Search strategy The search terms were social, problem(s), challenge(s), impact(s) or issue(s), swine production, pig production or pork production, and consumption. The first search used the terms soci* AND (problem* OR challenge* OR impact* OR issue*) AND (swine OR pig OR pork) AND product* AND consum*. In a second search, the terms were soci* AND (problem* OR challenge* OR impact* OR issue*) AND soy* OR rapeseed* OR canola. In the third search, the terms were soci* AND (problem* OR challenge* OR impact* OR issue*) AND (swine OR pig OR pork) AND (slaughter* OR abattoir*). The three searches resulted in 17,600; 18,900; and 18,000 citations, respectively.

Inclusion criteria A publication was included if it (i) was written in English; (ii) was a peer-reviewed article, commentary from a journal or NGO publication focusing on subject areas (e.g. The Dutch Soy Coalition); (iii) was published between 1998 and June 2019; (iv) had online full text available; and (v) had a title, excerpt, or statements with socio-economic issues related to one or more of the following: soy in Asia or South America, crop production in Europe, pig production in Europe or North America, and the slaughtering of pigs in Europe or North America. In addition, the reference lists from the identified publications were screened for any relevant literature.

Full-text assessment In the first screening, articles were excluded if they did not meet the inclusion criteria. The most common reason for exclusion was that the title did not refer to crop production, pig production, slaughter, or consumption. Pig production and slaughter issues were restricted to systems in developed countries. The first screening resulted in the selection of 14, 60, and 3 publications for the first, second, and third searches, as described above. The second screening was based on the full text of the articles. After duplicates had been excluded, the relevant publications were narrowed down to 2, 27, and 1 publications for the first, second, and third searches. In total, 30 publications were finally used to identify social sustainability issues. The social sustainability issues identified from the literature subsequently used in the computation of social risks are presented in Tables 3, 4, 5, 6, 7, and 8. (See the full list of social sustainability issues in the Online Resource, Tables 1–6).

Expert workshop A workshop with 13 experts in Swedish pork production, especially feeding, husbandry, pig health, and slaughter, was organized to verify social sustainability issues identified from the literature search, and to identify potentially relevant additional issues. Before the workshop, the experts were informed about the goal of the study and the social sustainability issues of pork production identified from the literature.

In the verification process, the experts first assessed the relevance of social sustainability issues in the context of Swedish pork production. Following group discussion, they reached a consensus on which of the issues identified in the literature search that were not relevant in the current context. These were excluded from the subsequent steps of the investigation. The experts also suggested additional social sustainability issues not captured by the literature search.

The social sustainability issues collected from literature review and stakeholder workshop were classified into subcategories based on the guidelines, as shown in Tables 3, 4, 5, 6, 7, and 8. The literature review and workshop together resulted in 35 subcategories (including subcategories for pigs) and 156 social sustainability issues (social sustainability issues Tables 1–6 in the Online Resource).

2.2 Life cycle inventory

2.2.1 Activity variables

To relate the impacts from the different subsystems to the functional unit, different activity variables (T) were used (UNEP 2009; Section 2.3.3). The activity variable for *workers* and *farmers* was work hours, i.e. the number of hours of work for one person at the farm and the slaughterhouse needed to produce the functional unit. In the calculation of the activity variables (T) for the pig farm, we added (T) for home-grown cereals with (T) for pig production. For example, work hours needed to produce the functional unit for the *workers* in the organic pork system are 7.4 h (6.17 h for pig production and 1.18 h for home-grown cereals). For *pigs*, the unit was life days at the *pig farm* and the *slaughterhouse*. Pig life days are given by the number of pigs needed to produce the functional unit multiplied by days at *the farm* or at *the slaughterhouse*. We assumed mortality was on the first day for piglets and at 50% of production time for weaners, growers, fatteners, gilts, and sows. For *local community* and *society*, the activity variables were people hectare days calculated as the number of people in an area (defined in square kilometers see Section 2.1.5) multiplied by the number of hectares used in the production process and the number of days of the production process used to produce the functional unit.

Table 3 Issues from the literature and experts for the stakeholder category *workers*

Subsystem	Subcategory	Inventory indicator	Social sustainability issue
Soybean farm	Freedom of association and collective bargaining	Global Rights Index workers	Organization freedom and union[a]
	Child labour	Child labour percentage	Poor application of the UN Convention on the Rights of the Child[a]
	Fair salary	Minimum wage	Low wages (The Dutch Soy Coalition 2008)
	Working hours	Work hours per week	Long working hours[a]
	Forced labour	Global Slavery Index	Slavery (The Dutch Soy Coalition 2008)
	Equal opportunities/discrimination	Gender Equality Index	Gender inequality at farms[a]
	Health and safety	Hospital beds per 1000 inhabitants Physicians per 1000 inhabitants	Limited access to health services (The Dutch Soy Coalition 2008)
		Percentage of DNA damage in leucocytes of farm and office workers	Risk of cancer from pesticide use (Walker et al. 2005)
		Adult literacy rate	Poor training of workers on management of chemicals, safety, first aid and waste management on farms[a]
	Social benefits and security	Percentage of unemployed receiving social security unemployment benefits Public social protection expenditure on benefits	Unsatisfactory social benefits (Zortea et al. 2018)
Rapeseed farm	Fair salary	Lowest wage	Low wages[b]
	Working hours	Work hours per week	Long working hours[b]
	Forced labour	Global Slavery Index	Slavery[b]
	Equal opportunities/discrimination	Gender Equality Index	Gender inequality at farms[b]
	Health and safety	Hospital beds per 1000 inhabitants Physicians per 1000 inhabitants	Limited access to health services[b]
Pig farm	Fair salary	Average wage per month	Lower salary for pig caretakers due to rise of industrial pig production (Honeyman 1996)
	Working hours	Work hours per week	Long working time (Porcher 2011)
	Health and safety	Percentage with respiratory disease	Respiratory diseases (Donham et al. 2006; Preller et al. 1995)
		Risk of antibiotic resistance	Antibiotic resistance (methicillin-resistant *Staphylococcus aureus*—MRSA) (Van Boeckel et al. 2015)
		Percentage of farm workers with musculoskeletal disorders (MSD)	Musculoskeletal disorders (MSD)[a]
		Accidents per 1000 workers	Accidents[a]
	Social benefits and security	Percentage of unemployed receiving social security unemployment benefits Public social protection expenditure on benefits	Rare paid sick leave on pig farms (Porcher 2011)
Slaughter house	Fair salary	Average wage per month	Low wages (Dillard 2008)
	Working hours	Work hours per week	Long working time (Dillard 2008)
	Equal opportunities	Ratio of females to males employed Percentage gender salary gap	Gender inequality[a]
	Health and safety	Accidents per 1000 workers	Accidents—physical danger from sharp knives (Dillard 2008)
		Work related sickness per 1000 workers	Work related sickness (musculoskeletal disorders, tendonitis, carpal tunnel syndrome, white finger, psychological traumatic stress) (Dillard 2008)

[a] Input from the workshop (subcategories without the footnote are from the guidelines and social sustainability issues without the footnote are from the literature search)

[b] All social sustainability issues identified for the soybean farm were also listed for the rapeseed farm

Table 4 Issues from experts for the stakeholder category *farmer* (new stakeholder)

Subsystem	Subcategory	Inventory indicator	Social sustainability issue
Pig farm	Freedom of association	Difference in proportion of farmers with freedom of association	Organization freedom and union[a]
	Fair income[a]	Average income per year	Lower income[a]
	Working hours	Work hours per week	Long working time[a]
	Health and safety	Risk of antibiotic resistance	Antibiotic resistance (methicillin-resistant *Staphylococcus aureus*)[a]
		Percentage of farmers with musculoskeletal disorders (MSD)	Musculoskeletal disorders (MSD)[a]
		Accidents per 1000	Accidents[a]
	Social benefits and security	Proportion of farmers with access to social benefits	Rare paid sick leave on pig farms[a]
	Work satisfaction[a]	Percentage of farmers with low status	Low status and recognition in society[a]

[a] Input from the workshop (subcategories without the footnote are from the guidelines and social sustainability issues without the footnote are from the literature search)

Standard pig diets for the two systems were used to compute the time needed for the production of 1000-kg pork. For the conventional pork system, the pig diet was obtained from Cederberg et al. (2009) as this was the best available estimate. The organic diet, for which there is no official published data available, was provided by a feed company with good knowledge about feeding practices in organic pork production in Sweden (anonymous, so as to respect confidentiality). Consumption is indicated by the number of people consuming pork (without bones) in one day and is obtained by dividing 1000-kg pork by the average pork consumption per capita per day, which is 40 g in Sweden (Åsa Öberg Jordbruksverket personal communication 26 May 2020). The activity variable for consumers was people consumption days. Soybean and rapeseed production produce oil as a co-product. Economic allocation was used for these co-products for the allocation of social risk. We used a factor of 0.60 for soybean meal/cake (Cremaschi et al. 2015) and 0.24 for rapeseed meal/cake (Bernesson 2004). Table 9 shows the activity variables associated with the production and consumption of 1000-kg pork for different stakeholders.

2.2.2 Inventory indicators

Data for the inventory indicators for social sustainability issues were collected from case-specific and generic sources. Case-specific data were collected from interviews, survey data, published articles, reports, and websites. Data for the subsystems *pig farm* and *slaughterhouse* were mainly case-specific. For imported feed, which was not possible to trace to a very specific origin, generic data were used. For some *soybean farm* and *rapeseed farm* inventory indicators, we used national data (rather than sector specific) as a proxy due to lack of data. For example, for social benefits and security at *soybean farm*, the percentage of unemployed receiving social security unemployment benefits in the soy-producing country was used as a proxy. The national data were collected mainly from reports and databases from international organizations such as ILO (International Labour Organization), the World Bank, United Nations agencies, and third party certification agencies.

2.2.3 Weighting

Expert weighting of subcategories was used in the assessment for each subsystem for each stakeholder. For example, for the stakeholder category *workers* in the subsystem *pig farm*, the four subcategories, fair salary, working hours, health and safety, and social benefits and security, were used (Table 3). These subcategories were then weighted using Analytical Hierarchical Processing (AHP) (Saaty 1990). AHP was conducted through a questionnaire for each stakeholder category and subsystem. In total, 15 stakeholders-subsystems were included in the study (Table 1), and with only one subcategory for *local community* for *slaughterhouse*, 14 questionnaires were used in total. The experts were selected based on purposive sampling with requirements of a minimum of two and a half years' work experience in the subject area. The experts included farmers and staff from advisory services, authorities, academia, and NGOs. Invitations to respond to a web-questionnaire using Netigate (a Swedish web-based survey tool) were sent by email to 10 experts for each questionnaire. The aim was to obtain at least three responses for each questionnaire. Experts with suitable expertise were invited to answer several questionnaires. Examples of invitation emails and questionnaires can be found in Questionnaires 4.1–4.4 in the Online Resource. The pairwise comparisons made by experts were used to make geometric mean vectors using AHP in the R package (AHP).

The consistency ratio for an expert should ideally be ≤ 0.1 according to Saaty (2003, 1990), but a consistency ratio ≤ 0.2 can be accepted in applied sciences (Dolan 2008). For any

Table 5: Issues from the literature and experts for the stakeholder category *local community*

Subsystem	Subcategory	Inventory indicator	Social sustainability issue
Soybean farm	Access to material resources	Percentage change in forest area 2000–2010	Deforestation (deVisser et al. 2014; The Dutch Soy Coalition 2008)
	Delocalization and migration	Land holding inequality Gini Index	Delocalization due to expanding soybean farms and land grabbing/land speculation (The Dutch Soy Coalition 2008)
	Cultural heritage	Food production diversity score	More cash crop production by small-scale farmers at the expense of more traditional crops (The Dutch Soy Coalition 2008)
	Safe and healthy living conditions	Active ingredient per ha	Human and environmental pesticide toxicity from pesticides and herbicides (The Dutch Soy Coalition 2008)
Rapeseed farm	Delocalization and migration	Percentage employed in the agricultural sector	Delocalization to urban areas due to fewer and larger farms[b]
	Safe and healthy living conditions	Active ingredient per ha	Human and environmental toxicity from pesticides and herbicides[b]
Pig farm	Access to material resources	Percentage of farms below 100 ha	Community assistance from farmers, for example snow clearance[a]
		Percentage of farms above 100 ha	Large farms results in improved infrastructure (installation of internet infrastructure etc.)[a]
		Percentage of farms with stores	Access to farm stores[a]
	Delocalization and migration	Percentage change in farms above 100 ha	Reduction in number of family farms due to industrial pig production (Honeyman 1996)
	Cultural heritage	Percentage of pigs kept indoors throughout life	Pigs kept indoors and not seen outside (Boogaard et al. 2011)
Slaughter house	Access to material resources	Average of water use per tonne pork	High amount of water use (Gerbens-Leenes et al. 2013; Urlings et al. 1992)

[a] Input from the workshop (subcategories without the footnote are from the guidelines and social sustainability issues without the footnote are from the literature search)

[b] All social sustainability issues identified for the soybean farm were also listed for the rapeseed farm

expert with a consistency ratio > 0.2, we used the R package Ahpsurvey to develop an error matrix iteration (Harker 1987) to replace inconsistent values in order to reduce the consistency ratio until this was ≤ 0.2. In the aggregation of individual weights, we used the geometric mean of all respondents (within the same questionnaire), as this is more appropriate for the AHP method than the arithmetic mean (Forman and Peniwati 1998). Between 3 and 6 responses per questionnaire were obtained from the 10 invited experts.

2.3 Life cycle impact assessment

2.3.1 Social Risk

In this study, the Social Risk (SR) is a measure of the risk of negative social impacts for each of the inventory indicators related to the social sustainability issues listed in Tables 3, 4, 5, 6, 7, and 8. SR corresponds to the risk weighting factor R_i representing the risk of negative social impacts in Tallentire et al. (2019) and Benoit et al. (2012). SR also corresponds to the normalized value for an indicator N_i used by Chen and Holden (2018) in the assessment of sustainability. SR is not corrected for the functional unit. SR, ranging between 0 and 1, is a normalization of the inventory indicator using reference points (see computation of social risk in the Online Resource in Tables 10–24). A reference point denotes a baseline situation for a certain aspect. SR is 0.5 when the inventory indicator is at the reference point. If for a certain inventory indicator, the situation is worse than for the reference point, the value of SR will be between 0.5 and 1. Hence, a low value of SR is preferable, as it means a low risk of negative social impacts. For example, for the social sustainability issue 'long working hours', the inventory indicator is work hours per week. If the work hours per week is above the average in Europe (the performance reference point), that would give a score above 0.5. If the inventory indicator is better than the reference, the SR will be between 0 and 0.5. The formulas used to calculate SR were:

1) $\mathrm{SR} = 1 - \mathrm{EXP}(\mathrm{LN}(0.5) \times \mathrm{IND}/\mathrm{REF})$ when a *higher* value than the reference point reflects a more negative impact, and
2) $\mathrm{SR} = \mathrm{EXP}(\mathrm{LN}(0.5) \times \mathrm{IND}/\mathrm{REF})$ when a *lower* value than the reference point reflects a more negative impact.

where IND is the inventory indicator for the subsystem and REF is the reference point.

The reference points used in this study were based on European averages (reference frame Table 8 in the Online Resource). The reference points were collected from the literature; see Tables 10–24 in the Online Resource. For example, the number of hospital beds per 1000 inhabitants in Europe, 5.6 beds (World Bank 2019), was used as the reference point

Table 6 Issues from the literature and experts for the stakeholder category *consumers*

Subsystem	Subcategory	Inventory indicator	Social sustainability issue
Consumption	Health and safety	Meat consumption per capita	Health Obesity due to pork consumption (Walker et al. 2005) Cardiovascular disease due to excessive meat consumption (Walker et al. 2005) Type II diabetes due to excessive meat consumption (Walker et al. 2005) Cancer due to excessive meat consumption (Grunert et al. 2018)
		Risk seroprevalence of *Toxoplasma gondii* infected meat	Food safety *Listeria* sp. infection from meat (Davies 2011; Mcglone 2013) *Escherichia coli* infection from meat (Hansen et al. 2013; Mcglone 2013) *Salmonella* sp. infection from meat (McGlone 2013) *Campylobacter* sp. infection from meat (McGlone 2013) *Yersinia enterocolitica* infection from meat (Drummond et al. 2012) Hepatitis E virus infection from meat (Wacheck et al. 2012) *Toxoplasma gondii* infection from meat (Kijlstra et al. 2004) Antibiotic resistance from meat (Van Boeckel et al. 2015)
	Perception of value[a]	Price per kg carcass	Low economic value of pork meat[a]
	Affordability[a]	Price per kg carcass	High price of pork (Mcglone 2013)
	Extrinsic attributes[a]	Percentage of pork products with a label indicating extrinsic quality	Known origin of the meat (Bernués et al. 2003)
	Eating quality[a]	Ultimate pH (pork)	Low quality of meat (Boogaard et al. 2011)

[a] Input from the workshop (subcategories without the footnote are from the guidelines and social sustainability issues without the footnote are from the literature search)

to compare access to health services in China, Brazil, and Italy for soy workers. European reference points were used because Europe is, in an international context, a champion of sustainability (European Commission 2019). However, for fair wage, which depends on the living costs in a specific country, national minimum wages in each country were used as reference points. Where average values were not available, control values were used as reference points. For example, percentage of DNA damage of leucocytes in sedentary workers was used as a control for DNA damage of leucocytes in farm workers using pesticides. The reference point for each inventory indicator is described in more detail in the Online Resource (computation of social risk Tables 10–24). Where no performance reference points could be found in the literature, for example, as happened with average prevalence of Listeria species in Europe, expert judgement was used for estimating the SR. These estimates were based on an ordinal scale: very low risk = 0.1, low risk = 0.3, average risk = 0.5, high risk = 0.7, and very high risk = 1.

To calculate SR in subsystems with two subprocesses producing the same product, for example, the *soybean farm* in the organic pork system, where soybean produced both in Italy and China was used, we used mass allocation factors in calculating SR for the *soybean farm*, i.e. 0.47 for Italy and 0.53 for China (feed company, anonymous personal communication 1 November 2018). For the rapeseed farm in the conventional pork system, we used 0.18 for Sweden and 0.82 for Denmark (Cederberg et al. 2009) as mass allocation factors for SR. The factors are based on the ratios of the soybean and rapeseed in the diets.

2.3.2 Weights

The weight for a subcategory (see Section 2.2.3 on how weights were collected from AHP) was multiplied by the weight for the inventory indicator (all inventory indicators under subcategory were assigned equal weight), giving the final weight (W) for each inventory indicator. For example, the subcategory health had a weight of 0.370 and had four inventory indicators (percentage of workers with respiratory diseases, risk of antibiotic resistance, percentage of workers with musculoskeletal disorders, and accidents per 1000 workers) as shown in Table 12 in the Online Resource. Thus, the final weight (W) for each inventory indicator would be 0.370 × 0.25 = 0.0925.

2.3.3 Social Risk Time

The social risk depends on the extent an input is used or the magnitude of 'exposure'. The social risk related to an input used in either of the two systems will differ depending on the quantity of the input used to produce the functional unit (for example, 4511 kg of wheat is required in the feed in order to produce 1000 kg of pork in the conventional pork system while 5566 kg of wheat is required in the organic pork system). This is true not only for quantities but can also refer to the magnitude of exposure, for example, the number of days a pig is exposed to negative social impacts in different subsystems vary between pork production systems. In accordance with Tallentire et al. (2019), the social risk for subsystems and stakeholders was

Table 7 Issues from the literature and experts for the stakeholder category *pigs* (new stakeholder)

Subsystem	Subcategory	Inventory indicator	Social sustainability issue
Pig farm	Animal-friendly housing[a]	Percentage of pigs with access to daylight	Daylight for pigs (Boogaard et al. 2011)
		Percentage of pigs with slatted floors	Slatted floors (Pedersen 2017)
		The indoor space per pig	Freedom to move (Boogaard et al. 2011)
		Percentage of time a pig spends in an outdoor environment	Outside access (Boogaard et al. 2011)
		Percentage of pigs provided enrichment material	Distraction material straw (Boogaard et al. 2011)
		Months per year a sow spends in a crate	Crated sows[a]
	Possibility to express natural behavior[a]	Percentage of pigs provided roughage as feed	Absence of roughage (Boogaard et al. 2011)
		Percentage of pigs with bitten tails	Evidence of tail biting (Sinisalo et al. 2012; Walker and Bilkei 2006; Valros et al. 2004)
		Access outdoor area or deep straw bed	Possibility to express natural behaviour—rooting, playing, and lying in the mud (Boogaard et al. 2011)
	Free from fear, pain, and injuries[a]	Injuries per pig	Scared, stressed, injured, and ill animals (Boogaard et al. 2011)
	Good animal health[a]	Percentage of pigs with osteochondrosis	Osteochondrosis[a]
		Percentage of pigs with Erysipelas	Swine erysipelas[a]
		Pig mortality	Piglet mortality (Bergstra et al. 2017)
		Percentage of pigs with pneumonia	Lung disease[a]
		Percentage of pigs with internal parasites	*Ascaris suum* (Sutherland et al. 2013)
		Prevalence of shoulder lesions	Shoulder lesions[a]
		Weaning age	Weaning age (Bergstra et al. 2017)
	Animal friendly management[a]	Percentage of tail docked pigs	Tail docking (Bergstra et al. 2017; Boogaard et al. 2011)
		Percentage of pigs with nose rings	Use of nose rings (Boogaard et al. 2011)
Slaughterhouse	Free from fear, pain and injuries[a]	Percentage of pigs with injuries	Injuries due to fighting at slaughter house especially overnight[a]
	Animal friendly management[a]	Ultimate pH	Stress in pigs at slaughter, poor meat quality (an indicator of stress), fear/stress due to transport, and handling before slaughter (Carlsson et al. 2007)

[a] Input from the workshop (subcategories without the footnote are from the guidelines and social sustainability issues without the footnote are from the literature search)

computed as Social Risk Time (SRT) using the activity variables (*T*) needed in each subsystem to produce the functional unit, the score for each inventory indicator (SR), and the weight of each inventory indicator (*W*). The SRT were summed over inventory indicator to give the SRT for stakeholder *i* (e.g. *worker*) and subsystem *j* (e.g. *soybean farm*) as:

$$\mathrm{SRT}_{ij} = \sum_{k=1}^{K} \left(T_{ij} \times \mathrm{SR}_{ijk} \times W_{ijk} \right)$$

where *k* denotes inventory indicator (e.g. $k = 1\ldots.12$ for *workers* at *soybean farm*), SRT_{ij} denotes Social Risk Time for stakeholder *i* in subsystem *j*, T_{ij} denotes the activity variable in subsystem *j* for stakeholder *i* (e.g. work hours), SR_{ijk} denotes the Social Risk for inventory indicator *k* in subsystem *j* for stakeholder *i*, and $W_{ijk}$is the weight of inventory indicator *k* in subsystem *j* for stakeholder *i*. SRT for all relevant subsystems were also summed to a total SRT for each stakeholder as shown in Table 9.

2.3.4 Social Hotspot Index

The Social Hotspot Index (SHI) indicates the risk of negative social impacts relative to the maximum possible risk of negative social impacts for a given stakeholder in one of the systems (Benoit et al. 2012). Following Tallentire et al. (2019) and Benoit et al. (2012), we calculated the SHI based on the assessed SRT relative to the worst potential SRT for a system, $\widehat{\mathrm{SRT}}$, which occurs when SR = 1. SHI values range between 0 and 1, and a low value of SHI is preferable as it indicates a low potential of negative social impact. The formula for the Social Hotspot Index for stakeholder *i* in subsystem *j* is:

$$\mathrm{SHI}_{ij} = \mathrm{SRT}_{ij} / \widehat{\mathrm{SRT}}_{ij}$$

Table 8 Issues from the literature and experts for the stakeholder category *society*

Subsystem	Subcategory	Inventory indicator	Social sustainability issue
Soybean farm	Public commitment to sustainability	Ecosystem status	Commitment to environmental sustainability: deforestation, loss of biodiversity, erosion, and degradation
	Contribution to economic development	Hours per hectare	Low employment due mechanization of crop cultivation (The Dutch Soy Coalition 2008)
	Contribution to food production/security[a]	Yield per hectare	Low productivity per hectare[a]
Rapeseed farm	Public commitment to sustainability	Ecosystem status	Commitment to environmental sustainability: deforestation, loss of biodiversity, erosion, and degradation[b]
	Contribution to economic development	Hours per hectare	Low employment due mechanization of crop cultivation[b]
	Contribution to food production/security[a]	Hectares per tonne	Low productivity per hectare[b]
Pig farm	Public commitment to sustainability issues	Proportion of human edible component	High food/feed competition (Walker et al. 2005)
		Percentage of farms with resistant *E. coli*	Contribution to antibiotic resistance[a]
		Cross Local Index	Reduction of the animal genetic variability (Nardone and Gibon 2015)
	Contribution to economic development	Percentage of farmers less than 35 years	Aging of pig farmers (Honeyman 1996)
		Hours per tonne pork	Low employment (work hours per 1000-kg pork)[a]
	Contribution to food production/security[a]	Carcass meat production (kg) per sow	Low productivity per sow[a]

[a] Input from the workshop (subcategories without the footnote are from the guidelines and social sustainability issues without the footnote are from the literature search)

[b] All social sustainability issues identified for the soybean farm were also listed for the rapeseed farm

where SRT_{ij} denotes Social Risk Time for stakeholder i in subsystem j, and $\widehat{\text{SRT}}_{ij}$ denotes the worst SRT for stakeholder i in subsystem j. The SHI for each stakeholder was then obtained by summing over subsystems taking into account the proportion of the total time in each subsystem such that $\text{SHI}_i = \frac{\sum_{j=1}^{J}\text{SHI}_{ij}\times T_{ij}}{\sum_{j=1}^{J}T_{ij}}$. An example of how SRT and SHI were calculated is presented in Table 9 in the Online Resource.

2.4 Interpretation

The interpretation step analyzed SR, SRT, and SHI to draw out conclusions on the risk of negative social impacts of pork systems in Sweden. SR shows social risks for different inventory indicators in relation to the reference without relating the impact to the functional unit, which is done for SRT and SHI. The fundamental difference between SRT and SHI is that SRT increases with the activity variable (e.g. work hours or pig life days) needed to produce the functional unit, while SHI only uses the activity variable to aggregate impacts from different subsystems.

3 Results

3.1 Social Risk

SR measures the risk of negative social impacts when relating the value of an inventory indicator in relation to a reference point. A value lower than 0.5 indicates a better situation than the reference, which is the average European social conditions. For stakeholder *workers* at the *soybean farm*, 8 of 12 inventory indicators had a value of SR > 0.5 in the conventional pork system and 5 of 12 had a value of SR > 0.5 in the organic pork system (Table 9). This was due to aspects related to human rights and social security in the countries in which the soy is produced (see details in Table 10 in the Online Resource). For example, for the inventory indicator *percentage of unemployed receiving social security unemployment benefits*, the conventional pork system had higher values of SR than the organic due to lower social security in Brazil (conventional soy) than in China and Italy (organic soy). For *workers* at the *slaughterhouse*, 2 out of 6 inventory indicators had a value of SR > 0.5 in both pork systems. However, the highest value of SR of all 32 inventory indicators (in all subsystems) for *workers* was at the *slaughterhouse* for both

Table 9 Activity variables, Social Risk (SR), Social Risk Time (SRT), and Social Hotspot Index (SHI) for stakeholders for 1000 kg of consumed pork

Stakeholder category and subsystem	Activity variables		Number of inventory indicators with Social Risk > 0.5 out of total inventory indicators		Social Risk Time		Social Hotspot Index	
	Conventional	Organic	Conventional	Organic	Conventional	Organic	Conventional	Organic
Workers	13	79	16/32	13/32	5.7	29	0.40	0.31
Soybean farm	1.6	58	8/12	5/12	0.64	20	0.24	0.27
Rapeseed farm	0.18	0.13	2/6	2/6	0.07	0.05	0.11	0.10
Pig farm	9	19	4/8	4/8	3.7	7.9	0.42	0.42
Slaughterhouse	2.7	2.6	2/6	2/6	1.3	1.3	0.48	0.48
Farmers	29	61	3/8	3/8	15	29	0.52	0.48
Local commun.	4900	24,000	7/12	2/12	2200	5,000	0.42	0.20
Soybean farm	250	1900	3/4	0/4	120	360	0.27	0.14
Rapeseed farm	310	160	1/2	1/2	160	57	0.13	0.09
Pig farm	4300	22,000	3/5	1/5	1900	4,600	0.45	0.21
Slaughterhouse	47	47	0/1	0/1	15	15	0.32	0.32
Consumers	25,000	25,000	2/16	2/16	9000	7500	0.36	0.30
Pigs	5000	5300	5/21	3/21	1700	1200	0.34	0.22
Pig farm	5000	5300	5/19	3/19	1700	1200	0.34	0.22
Slaughterhouse	0.51	0.51	0/2	0/2	0.25	0.15	0.48	0.30
Society	3,200,000	16,000,000	7/12	5/12	1,700,000	7,600,000	0.48	0.46
Soybean farm	170,000	1,300,000	1/3	0/3	59,000	380,000	0.21	0.23
Rapeseed farm	210,000	110,000	2/3	2/3	130,000	68,000	0.17	0.15
Pig farm	2,900,000	15,000,000	4/6	3/6	1,500,000	7,200,000	0.53	0.49

Values for the workers and farmers for the pig farm include wheat and barley production

systems, specifically for the inventory indicator *accidents per 1000 workers* (0.95), which was due to the high risk of accidents from sharp knives (Table 13 in the Online Resource*)*. For *farmers* at the *pig farm*, 3 out of 8 inventory indicators had a value of SR > 0.5 in both pork systems. This was due to low income, long working time and musculoskeletal disorders (Table 14 in the Online Resource). For *local community*, there were 5 inventory indicators for the *pig farm.* Three of these inventory indicators had a value of SR > 0.5 in the conventional pork system while only one had a value of SR > 0.5 in the organic pork system because of low SR related to community assistance, access to farm stores and pigs on pasture (Table 17 in the Online Resource). The highest value of SR for the *local community* was for the social sustainability issue *access to farm stores* at the *pig farm*. Of the 19 inventory indicators for stakeholder *pigs* at the *pig farm*, 5 in the conventional pork system and 3 in the organic pork system had a value of SR > 0.5. This was attributable to piglet mortality and other animal welfare issues (Table 20 in the Online Resource). The highest value of SR (0.91) for *pigs* was observed for the inventory indicator *percentage of pigs provided roughage as feed* in the conventional pork system. Roughage provides both nutrients and enrichment of the pigs' environment indoors. It is not provided in the conventional system while this is a requirement according to the organic certification. Of the 6 inventory indicators for stakeholder *society* at the *pig farm*, 4 in the conventional and 3 in the organic pork system had a value of SR > 0.5. This concerned sustainability issues related to farm animal genetic diversity, food/feed competition, and low productivity for both systems and also to aging farmers in Sweden for the conventional system (Table 24 in the Online Resource). The highest value of SR of all inventory indicators for the stakeholder *society* was for the social sustainability issue *reduction of animal genetic variability* at the *pig farm* and this was due to the lack of local, traditional breeds in Swedish pig production.

3.2 Social Risk Time

SRT relates the risk of negative social impacts to the functional unit taking the magnitude of 'exposure' and the weights of the inventory indicators into account. For *workers* in the organic pork system, the *soybean farm* had substantially higher value of SRT than all other subsystems (Table 9). This was due to organic production of soybean being time-consuming and carried out in countries with poor social security. For the stakeholder *workers* in the conventional pork system, the *pig farm* had the highest value of SRT because most of the work time for *workers* in the conventional pork production occurs at the *pig farm*. For the stakeholder *pigs*, SRT was dominated by the effects at the *pig farm* since pigs spend very little time at the *slaughterhouse*. For *local community* in both systems, the *pig farm* had the highest value of SRT because more land was required to produce wheat and barley than for soybean and rapeseed. For *consumers*, the inventory indicator for the subcategory 'extrinsic attributes' had the highest weight. The SR for the indicator in this subcategory was lower than 0.5 for both systems due to all organic production and 55% of conventional production being certified with a certification guaranteeing added extrinsic values for the consumer (Table 19 in the Online Resource).

3.3 Social Hotspot Index

SHI indicates the risk of negative social impacts relative to the worst case scenario for a given stakeholder and/or subsystem. Note that the activity variable in the calculation of SHI for each subsystem is cancelled out (see example in Table 9 in the Online Resource). This is illustrated by the SHI for *workers* at the *pig farm*, where SHI is the same for both systems (0.42) although SRT has a much higher value in the organic pork system due to longer work time needed to produce organic pork in comparison with conventional pork. In the conventional pork system, SHI > 0.5 slightly for *farmers* as well as *society* at *pig farm* which means a similar risk of negative social impacts with the average European social conditions. In the organic pork system, SHI < 0.5 (i.e. better than the average European social conditions) for all stakeholders and subsystems. Furthermore, the organic pork system had substantially lower values of SHI than the conventional pork system for *pigs* at *pig farm* and *slaughterhouse*. The organic pork system also had substantially lower values of SHI than the conventional pork system for stakeholder *local community* at *soybean farm* and *pig farm*. For *local community* at the *pig farm*, all 5 inventory indicators had approximately the same weight and the organic pork system had equal or lower values of SR for four of them (as compared with the conventional pork system). They were related to infrastructure, farm stores, reduction in family farms, and pigs seen outdoors (Table 17 in the Online Resource). These low values of SR resulted in a SHI for *local community* at *pig farm* of 0.21 in the organic pork system, as compared with 0.45 in the conventional pork system. Looking at the pork systems at an aggregated stakeholder level (in Table 9), the results show that *farmers* and *society* had the highest value of SHI in both systems.

4 Discussion

To our knowledge, this is the first S-LCA study of pork production. This is also the first study that includes the animals themselves (*pigs*) and *farmers*, together with stakeholders suggested by the guidelines (*workers*, *local community*, *consumers*, and *society*). Scherer et al. (2018) and Tallentire et al. (2018) presented studies where integration of animal welfare into social sustainability assessments has been done but these did not include any other stakeholders. It may be argued that considering animals as stakeholders in S-LCA is questionable since the area of protection in the S-LCA is humankind. However, as Tallentire et al. (2019) discuss, excluding animals in a sustainability assessment of the agrifood sector potentially excludes significant issues. Similarly, it can be argued that 'nature' (wild animals, plants and other species) should also be included as a stakeholder in the S-LCA (Chapron et al. 2019). Nature as such was not included in this S-LCA, but our plan is to combine social and environmental life cycle assessments of animal production systems in the future in order to identify potential synergies and goal conflicts between the environmental and the social dimensions of sustainability. Relating the potential social impacts to a functional unit in the S-LCA, as we did here, will facilitate a combined assessment of social and environmental sustainability.

In this study, we used three types of measures to quantitatively assess social risk: SR, SRT, and SHI. SR shows the risk of negative social impacts without relating to the functional unit. It can be valuable for identifying social sustainability issues that have a high risk of negative social impacts which do not show up in the overall assessment (e.g. due to a low value of the activity variable in the subsystem where they exist). For example, a single inventory indicator with a high value of SR can be enough to cause distrust in the system if this social sustainability issue is related to a claimed added value. In SRT, the SR values of different inventory indicators are weighed and aggregated at stakeholder and subsystem level, taking activity variables (e.g. work hours or pig life days) into account. SHI can help decision-makers to prioritize their efforts for increased social sustainability between stakeholders and subsystems. The results in this study suggest that *workers*, *farmers*, and *society* have the highest value of SHI in both systems.

In our study, we used the average European social conditions as the reference and SHI > 0.5 therefore means higher risks of negative social impacts than the average European social conditions. What is considered an acceptable level of negative social impact is highly normative and differs between stakeholders. In Sweden, Swedish pork is often marketed as being more sustainable than imported meat (see LRF 2015, for example). European pork production has advantages in a global perspective but there are still challenges (ATF 2019), and the average European production might not be considered 'good enough' as a bench mark for the conventional production system from a national perspective. Decision-makers working with pork systems with added values need to make a strategic choice; how far from the conventional pork system do they want to position their system (Rydhmer and

Slagboom 2017). The European organic movement has high ambitions in terms of animal welfare (IFOAM EU 2010). This is reflected in SRT and SHI for *pigs* at *pig farm* and *slaughterhouse* in the organic pork system. However, since their vision for food and farming is 'a fair, environmentally conscious, healthy and caring system' (Barabanova et al. 2015) one could expect lower values on SRT and SHI also for *farmers* and *society*. The difference in SRT between the organic and the conventional pork system is strongly related to the activity variables and thus resource efficiency, and potential goal conflicts between efficiency and sustainability needs further research.

The results of this study rests on the assumption that certification of soy (here the organic KRAV certification or the Round Table of Responsible Soy and ProTerra for conventional soy) can effectively decrease negative social risks when it comes to child labour, working hours, wage levels, and deforestation in Brazil, Italy, and China. However, these certifications have been criticized for being too weak to guarantee the preventions of negative impacts, especially for child labour (Jia et al. 2020). That is why we tested how results would be affected if we assume that this certification is not effective (see Table 10 and Table 15 for details). We found that the number of inventory indicators with a value above 0.5 increased from 16 to 17 and 13 to 15 for the conventional and organic systems respectively for the stakeholder *workers*. In terms of the SHI for *workers*, this increased to 0.42 for both systems (from 0.40 for the conventional and 0.31 for the organic). This indicates that if soybean certification is not effective, the SHI for *workers* in the two pork systems is closer to the European average. If certification of soybean does not work, for the stakeholder *local community* for the subsystem *soybean farm* for the conventional system, deforestation in Brazil emerged as a concerning issue scoring the worst possible, while the risk for deforestation is considerably lower in the countries from which organic soybean is sourced (China and Italy). Hence, results are sensitive to how well certification of soybean works.

When looking at the risk of negative social impacts in one system relative to another system, in some cases, it is sufficient to focus on SHI; while in other cases, it may be necessary to consider several measures including the activity variable (T) and the Social Risk Time (SRT), and examine how they interact with SHI. For example, a certain number of work hours (farmers and hired labour) are required in order to produce the functional unit of 1000-kg pork. This work can be more or less problematic from a social point of view. In our study, a resource-efficient production system, requiring fewer hours of work, but with a type of work associated with a more severe negative impact for some social sustainability issue (e.g. high rate of accidents), would result in a higher value of SHI than a system that requires more work hours but has less severe negative impacts for these social sustainability issues. SHI does not reflect the time of exposure for a certain impact. Tallentire et al. (2019) assess the welfare of broilers in four production systems (four countries) and they state that SHI is useful for identifying the risk of negative social impacts of a production system. The activity variable used in their study was, however, similar for the different systems whereas many of the activity variables (T) used in this study differed considerably between the conventional and the organic pork system. When the activity variables of two systems are not similar, then SHI and SRT provide complementary information important in assessing which of the systems has a relatively higher risk of negative social impacts. There are several possible outcomes to consider when comparing two systems, A and B, in case the activity variable is of greater magnitude for system A. If system A has a higher value of SHI and a higher value of SRT, this indicates that system A has a higher risk of negative social impacts. Conversely, if system A has a lower value of SHI and a lower value of SRT, this indicates that system A has a lower risk of negative social impacts. However, if system A has a lower value of SHI and a higher value of SRT, this indicates that the systems have similar risk of negative social impacts. If SHI is similar in both systems and the difference in SRT is small, then this indicates similar risk of negative social impacts.

The risk of negative social impacts has, in previous S-LCA studies on livestock products (eggs and dairy), been found to be largest for the stakeholders' *workers* and *local community* according to Pelletier (2018) and Chen and Holden (2017). The result of this study indicates that *farmers* and *society* are the stakeholders associated with the highest risk of negative social impacts. Our study differs from previous S-LCA on livestock products in that we included *farmers* as a separate stakeholder. In addition, we used different references; while previous studies have used the producing countries as reference; our reference was Europe. Since the reference is crucial for SR and thus the results of the evaluation, a sensitivity analysis of how different reference systems affect the results should be the next step.

For some social sustainability issues, neither case-specific nor generic inventory indicator data were available. The cost-benefit of collecting the data made us decide not to include all social sustainability issues in the final computation (e.g. the magnitude of noise at a pig farm for health and safety of workers). Of the 156 social sustainability issues identified in the literature search and expert workshop, 62% were finally used in this study. More inventory data would need to be collected and used in order to improve the quality of the S-LCA and to assure that the omission of social sustainability issues in this study does not mask substantial negative social impacts. We have reported all of the social sustainability issues collected from the literature and experts (social sustainability issues Tables 1–6 in the Online Resource), hoping that the long list will inspire other researchers to identify additional inventory indicators.

An important issue related to data on inventory indicators is change over time. Most production systems develop over time, and the use of old data on inventory indicators could therefore lead to problems of temporal conformance (Eisfeldt and Ciroth 2017). Discussions with different experts were conducted to mitigate this potential bias. Secondary data can also be influenced by other factors, unique to a study at a given time, and this increases uncertainty. A sensitivity analysis of how using different data sources affects the result is the next step in the improvement of this work.

The aggregation of various impact categories into an overall score requires the impact categories to be weighted. Ideally, the stakeholders—e.g. *farmers* and *consumers*—should do the weighting. Experts can also provide reliable results that are similar to those produced by stakeholders (Kamali et al. 2017). We used experts as proxy respondents because this was cheaper and faster than involving a large number of representatives of all stakeholders, and because obviously, the *pig*, as a stakeholder, cannot speak for itself. The results of this study may be influenced by the panel used. Future studies could check the robustness of our panel by using randomized large samples of the actual respondents—e.g. farmers or consumers. In the AHP, a consistency ratio ≤ 0.2 is desirable (Dolan 2008), but some experts' consistency ratios were larger than 0.2. Improving consistency by asking respondents to reconsider their choices could have offered a better way forward. However, there is a risk that the experts will get the impression that they are being pressed to revise their weighting in accordance with the researchers' preferences and lose interest in the whole study as a result. Hence, inconsistency was reduced with the method of Harker (1987), although this does not necessarily increase the validity of the matrix.

Ideally, the study of a system should include all inputs and outputs, but time and costs are always considered when defining system boundaries. Our system included wheat, barley, soy, rapeseed, and pig production. Future studies could expand the boundary, e.g. by including fertilizers which constitutes a major difference between organic and conventional pork systems. Fertilizers were not included in this study because we used the activity variables to cut off the system boundary. In future studies, production of fertilizers could be included by additional data on social sustainability issues and inventory data associated with fertilizer production. Farmers in conventional pork production use different diet compositions depending on the availability and price of feed ingredients during the course of the year. Data from a livestock feed inventory provided the best estimate currently available. Better and later data on the feed used would improve the quality of the study but requires a major study to collect such data. Family farms involving both the farmer and workers are common in Swedish pig production, and since they, to some extent, are concerned with different sustainability issues, both *farmers* and *workers* were included as stakeholders. In view of the difficulty of calculating the actual work hours for farmers in the other subsystems, we only included farmers for the pig farm. In future studies, we recommend that farmers are included for all subsystems.

In this study, we quantitatively examined the risk of negative social impacts in two pork production systems. Additional primary data is required in order to improve the assessment of the two systems and in particular to assess actual social impacts. This study does, however, show how the risk of negative social impacts of a functional unit in two different systems can be quantitatively analyzed and compared using the measures SR, SRT, and SHI. The findings can guide decision-makers within industry and society in their efforts to improve the social sustainability of livestock products.

5 Conclusions

The objective of this study was to assess the risk of negative social impacts in two pork production systems. An S-LCA was conducted on Swedish conventional and organic pork systems with high-performance crossbred pigs. The social risk was examined for stakeholders at two levels, the system and the subsystem. At the system level, the results indicate that for stakeholders' *workers*, *pigs*, *local community*, and *consumers*, both organic and conventional Swedish pork production have lower risk of negative social impacts than the average European social conditions. The risk of negative social impacts for the stakeholders' *farmers* and *society* was found to be the same as the average European social conditions.

At the subsystem level, the results indicate that *workers* as well as *society* at *soybean* farm have higher risk of negative social impacts in the organic pork system than in the conventional pork system. *Pigs* at *pig farm,* as well as *slaughterhouse*, and *local community* at the *rapeseed farm* and *consumers* have higher risk of negative social impacts in the conventional pork system than the organic system.

We conclude that Social Risk Time (SRT) and Social Hotspot Index (SHI) are measures useful for assessing the risk of negative social impacts within system and for comparing different production systems. A precise comparison between systems would however require additional primary data. The results from this study highlight social sustainability challenges in pork production and can help decision-makers prioritize between improvement opportunities. However, for the dependence of the results of the chosen reference level, the reliance on certification, and the indicators included, results should be interpreted and used with care. This study however provides useful information for future S-LCA of two or more livestock production systems.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent All experts gave their informed consent on the web questionnaire prior to answering the questions. No personal data was required, and therefore, there was complete anonymity of the responses.

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