Sustainable Production and Consumption 31 (2022) 52–66

Contents lists available at ScienceDirect

Sustainable Production and Consumption

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

Assessment of social aspects across Europe resulting from the insertion of technologies for nutrient recovery and recycling in agriculture

Edilene Pereira Andrade[a,b,*], August Bonmati[a], Laureano Jimenez Esteller[b], Assumpcio Anton Vallejo[a]

[a] Institute of Agrifood Research and Technology, Sustainability in Biosystems Research Program, Torre Marimon, Caldes de Montbui 08140, Barcelona, Spain
[b] Departament d'Enginyeria Química, Universitat Rovira i Virgili, Av. Països Catalans, 26, Tarragona 43007, Spain

ARTICLE INFO

Article history:
Received 27 November 2021
Revised 26 January 2022
Accepted 28 January 2022
Available online 2 February 2022

Editor: Prof. Shabbir Gheewala

Keywords:
S-LCA
Agriculture
Novel technologies
Nutrient recovery
PSILCA

ABSTRACT

The potential beneficial and harmful social impacts generated by the introduction of novel technologies, in general, and those concerning nutrient recovery and the improvement of nutrient efficiency in agriculture, in particular, have received little attention, as shown in the literature. This study investigated the current social impacts of agricultural practices in Belgium, Germany and Spain, and the potential social impacts of novel technologies introduced in agriculture to reduce nutrient losses. Based on 65 indicators used in the PSILCA database, the greatest impacts in the baselines are related to fair salaries, biomass consumption, industrial water depletion and public sector corruption. The potential social impacts of the technologies were assessed using 17 midpoint indicators that have a potential to affect social endpoints. The potential benefits of novel agricultural technologies were the creation of more attractive jobs in agriculture, and a better and healthier environment for local communities, workers and society. However, their harmful effects mainly related to workers and local community health, due to the substances used in the technologies and the potential gases emitted. Given the current lack of Social Life Cycle Assessment (S-LCA) studies on novel technologies in agriculture, this study is the first to use the PSILCA database to assess different technologies for nutrient recovery in agriculture in an initial and prospective assessment of their potential social impacts. Further work is required for a site-specific assessment of the technologies when a higher level of social adaptation is achieved.

1. Introduction

Food and agriculture production systems are facing unprecedented challenges due to the increasing demand for food for a growing population, rising hunger and malnutrition, adverse climate change effects, overexploitation of natural resources, loss of biodiversity, food loss and waste (FAO, 2021b). According to the European Commission (EC, 2021), the European Union (EU) is the world's largest importer and exporter of agri-food products, and the production of commodities are known to have negative environmental and social impacts.

Air pollutant emissions represent a key driver of air quality and ecosystem health, being agriculture responsible for 90% of ammonia emissions mainly from animal manure and fertiliser application (EEA, 2018). In addition, agriculture is one of the main sources of greenhouse gas (GHG) emissions, being responsible for 54% of total methane (CH_4) emitted in EU and approximately 79% of the total nitrous oxide (N_2O) emissions in 2020 (Mielcarek-bocheńska and Rzeźnik, 2021).

To be sustainable, agriculture must meet the needs of present and future generations while ensuring profitability, environmental health, and social and economic equity (Brundtland, 1987). According to the European Nitrogen Assessment (Sutton et al., 2011), ammonia emissions lead to losses of welfare and affect human health. Furthermore, nitrate levels in water resources around the world have increased due to intensive livestock farming and cropping, causing harmful biological effects such as cancer, thyroid disease, infant mortality, and birth defects (Sahoo et al., 2016; Ward et al., 2018). In addition, nitrous oxide emissions can contribute to decreasing lung function, respiratory hospital admissions and cardio-

* Corresponding author at: Departament d'Enginyeria Química, Universitat Rovira i Virgili, Av. Països Catalans, 26, Tarragona 43007, Spain.
E-mail address: edilene.pereira@irta.cat (E.P. Andrade).

https://doi.org/10.1016/j.spc.2022.01.025
2352-5509/

Nomenclature

CH_4	methane
DALYs	Disability Adjusted Life Years
EC	European Commission
EU	European Union
FAO	Food and agriculture organization
GHG	greenhouse gas
N_2O	nitrous oxide
PSILCA	Product Social Impact Life Cycle Assessment
SRL	Societal Readiness Level

vascular outcomes, while nitrogen dioxide has also been associated with adverse respiratory issues, for example coughing or shortness of breath (Levy, 2003).

In a view of the need to improve agriculture and reduce the impacts of nutrient emissions, nutrient recovery technologies will play a pivotal role in achieving these goals. Xia et al. (2020) reviewed current practices and future prospects in control technologies for nitrogen and phosphorous from agricultural runoff, highlighting that tillage practices (i.e., conservation and rotation) can significantly improve surface roughness and reduce surface runoff, also fertilisation management is another effective strategy to control nutrient losses, and process control technologies (i.e., microbial treatment technologies and constructed wetlands) aim to remove pollutants during agricultural runoff transport. In order to mitigate air emissions from agricultural practices, technologies as anaerobic digestion at farm scale, low nitrogen feed and precision farming have been applied (Fellmann et al., 2021).

Innovation in agricultural systems will have several beneficial environmental impacts. However, the associated social impacts may not be immediately apparent, particularly when they are a consequence of environmental benefits. For instance, introducing novel solutions in agriculture to reduce environmental impacts can create opportunities for growth and jobs for local communities, more training for workers, new strategies for the outputs (e.g. biogas production, recirculation of water) on farms, and systems and innovative options involving science, technology and policy. Furthermore, the inclusion of different solutions, some of them with high levels of technology and innovation, presents an opportunity to attract young and skilled workers, making agriculture more interesting to this section of population. However, it is not clear how adaptations and modifications to already established industries might evolve in a sustainable manner (Siebert et al., 2018).

Unfortunately, it is very difficult to obtain specific data to assess the social impacts over a life cycle, i.e. the whole production chain, in agriculture when compared with environmental assessments, leading to an imbalance between the three dimensions of sustainability (Darnhofer et al., 2010). However, there is growing awareness of the need for information on the social costs and opportunities of current activities and their related technological friendly alternatives (Darnhofer et al., 2010). Through the use of life cycle perspective and Life Cycle Assessment (LCA) it is possible to assess environmental loads of a product throughout its entire life cycle and the potential impacts of these loads on the environment (ISO 14040, 2006), being thus a valid tool for addressing the potential shifting of environmental consequences along the whole production chain.

The life cycle of a product involves the extraction of the raw material, the production and distribution of the product, its use and its final deposition, when the product is no longer used. Life Cycle Assessment (LCA) is a tool to investigate the environmental sustainability of the life cycle of products, with the possibility of also providing a social and economic sustainability by including two other tools, Social Life Cycle Assessment (referred to in the present work as S-LCA) and Life Cycle Costing (LCC) (Prasad et al., 2020). S-LCA has been shown to be a relevant methodology for the social evaluation of product systems, processes and services (Chen and Holden, 2017; Pelletier, 2018; UNEP, 2020). S-LCA helps to assess the socioeconomic impacts that directly and indirectly affect stakeholders during a product life cycle, providing short- and long-term information to help organisations better understand their current situation and development over time (Kühnen and Hahn, 2017; Arcese et al., 2018). The Guidelines for Social Life Cycle Assessment of Products and Organizations (UNEP, 2009) were updated in 2020 (UNEP, 2020), and are used to assess social and socio-economic impacts, both positive and negative, of products over their lifecycle.

A socioeconomic assessment may be even harder when it comes to the introduction of novel technologies. Van Haaster et al. (2017) discuss general considerations regarding S-LCA, proposing a framework to explore future potential impacts on social well-being arising from the inclusion of novel technologies, and offer a pioneering prospective S-LCA study. In the present study, an S-LCA using the Likert scale (Albaum, 1997) and expert opinions was used to identify the potential social impacts of the inclusion of solutions to recover nutrients in agricultural systems across Europe.

The objectives of this study were therefore:

- To screen social impacts in agricultural systems using S-LCA and an S-LCA database;
- Identify hotspots in agricultural product systems in Belgium, Germany and Spain using the Product Social Impact Life Cycle Assessment (PSILCA) database;
- To define a set of indicators to assess the social effects of technologies to reduce nutrient losses in agriculture;
- To test and evaluate the effectiveness of prospective assessments in S-LCA, carrying out a case study for three different technologies.

2. Methods

A pathway for the S-LCA performed in the present study is detailed in Fig. 1 following the Guidelines for Social Life Cycle Assessment of Products and Organizations (UNEP, 2020).

Scenario analysis has emerged as a way of characterising the future and its uncertainties through structured thinking. In addition, they have been defined as plausible and often simplified descriptions of how the future may develop based on a consistent set of assumptions considering key driving forces and relationships. The qualitative and descriptive assumptions within scenarios are called storylines, and they can describe the consequences or outcomes of a scenario (Rousenvell et al., 2010).

2.1. Baseline: agriculture profile using the PSILCA database

The baseline represents a minimum or starting point used for comparisons, that is, a business-as-usual scenario considered to compare with possible changes brought about in the evaluated system. In the current study, the baseline is assumed as to be a 'typical farm', without technologies no technology included to reduce nutrient losses, using the agricultural product system from PSILCA with no changes.

The goal of the first part of the study was to provide a screening analysis taking a country-specific approach using the Product Social Impact Life Cycle Assessment (PSILCA) database. PSILCA version 3 uses the multi-regional input/output database EORA, 2019 version, which covers the entire world economy. As with EORA, PSILCA uses money flows to link processes providing social impacts for around 15,000 sectors in 189 countries (Maister et al., 2020).

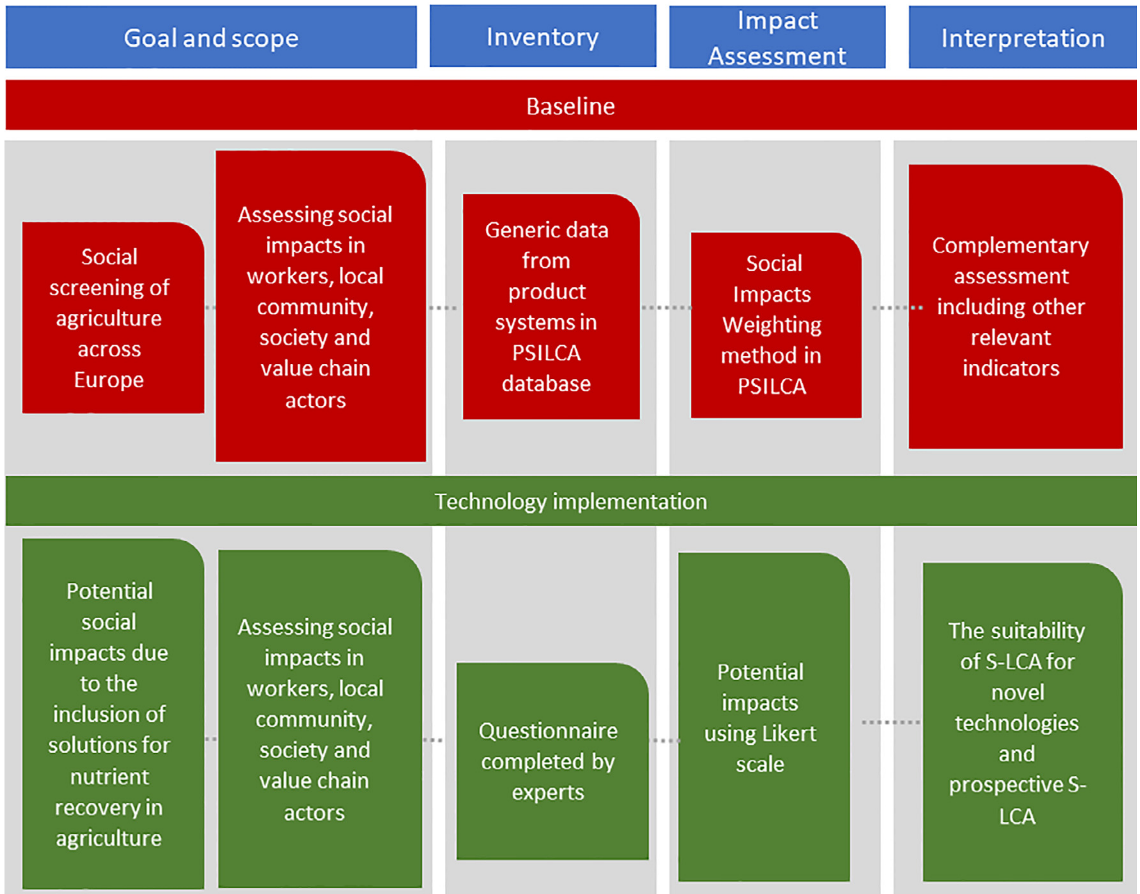

Fig. 1. Path followed to assess a baseline and scenarios created due to the inclusion of a novel technology in an agricultural system.

The PSILCA database is a global, consistent database, suitable to assess social impacts of products, along product life cycles, providing generic information on social aspects in country-sector combinations and commodities that can be used for screening purposes to identify high-risk regions (Maister et al., 2020; UNEP, 2020). In PSILCA, the sector and country-specific data are obtained from international institutions (e.g., World Bank, OECD, World Health Organization, Walk Free Foundation, ILOSTAT database) and attributed to the selected product systems and indicators. Using PSILCA, it is possible 'to measure' how externalities (e.g. corruption, child labour, trade unionism) affect or can be affected by the product being assessed (Kono et al., 2018; Werker et al., 2019a; Martin and Herlaar et al., 2021).

In the current study, 69 qualitative and quantitative indicators from PSILCA were used to calculate the social impacts of a baseline (current situation) in agriculture and also to identify social hotspots in the product systems (Maister et al., 2020). The indicators address stakeholders such as workers, local community, society and value chain actors. The indicators used in the PSILCA database include those recommend by UNEP-SETAC (Benoit-Norris, 2013).

The system boundaries and life cycle inventory are related to the product systems selected in the PSILCA database: 'Industries - Agriculture, hunting and related service activities' for Belgium, 'Industries - Agriculture and hunting' for Germany, and 'Industries - Agriculture, livestock, and hunting' for Spain. In EORA, each country uses its own classification system and sector names (Lenzen et al., 2013). Therefore, it is assumed that although the names of the products differ slightly, they are comparable in the context of agriculture. Belgium, Germany and Spain were selected because the technologies detailed in Section 3.2 have been developed and tested by experts there.

A cut-off of 1E-05 was applied in the impact analysis, which is the maximum detail in the version 'starter' of PSILCA (Maister et al., 2020). The results included all the sectors up to the fifth level of upstream processes, which is sufficient for the current study since the technologies evaluated (Section 2.2) have limited capacity to affect the production systems of other countries involved in the main product. No further modification was made to the product systems or indicators values provided by PSILCA.

The functional unit used was 1 USD of output of a generic agricultural product in the respective sectors, since it is intended to assess potential hotspots in the agricultural chain in the countries, and not a specific product. The activity variable was the number of hours required to generate 1 USD of product output, using USD from 2015 as reference. Although it may seem inappropriate to use dollars to assess the impacts for European systems, the dollar is the basis for transactions and is used in major commercial activities in the global economy.

The impact assessment was performed in the free software OpenLCA using the Social Impacts Weighting method from PSILCA, applying characterisation factors to each indicator according to its risk or opportunity created (Table 1). The assignment of risk and opportunity levels was based on international conventions and standards, labour laws, expert opinions and the literature (Maister et al., 2020). The risks represented the potential negative impacts, and the opportunities represented the potential positive impact. The indicator 'Contribution of the sector to economic de-

Table 1
Characterisation factors for the Social Impacts Weighting method in PSILCA retrieved from Maister et al. (2020).

Nature of indicator	Level	Factor
Risk	Very low	0.01
	Low	0.1
	Medium	1
	High	10
	Very high	100
	No risk	0
Risk/Opportunity	No data	0.1
Opportunity	Low	0.1
	Medium	1
	High	10
	No opportunity	0

velopment' was the indicator that assessed opportunities in PSILCA v3.

The total impact on each product system is the summation of the risks subtracted by the opportunities created. In addition, the indicators are also presented separately in Supplementary Material S2 so as not to lose transparency (UNEP, 2020). As explained in Werker et al. (2019b), the metric of medium risk hours (med risk hours) used in PSILCA to present the impact results is not measured on a particular scale (ranges classifying the impacts from very low to very high, for instance), hence it is necessary to compare different supply chains to make the results meaningful. Therefore, the results for this part of the study are presented for each country. Med risk hours represent the total risk involved in producing 1 USD of the output.

2.2. Definition of the novel technologies

The metric Societal Readiness Level (SRL) assesses the level of societal adaptation of a novel technology on a scale of 1 (less adapted) to 9 (more adapted) (Bruno et al., 2020). For the technologies included in this study, the SRL was 2. SRL 2 means that the problem is formulated (high environmental impact from agriculture), a solution is proposed (a novel technology to recover nutrients and enhance nutrient efficiency), and the expected societal readiness is defined (social impacts due to the inclusion of the technology in the agricultural scenario) and considers which stakeholders are relevant for the assessment (stakeholders directly and indirectly affected by agriculture and the novel technology developed). The inclusion of the SRL in the presentation of technologies is necessary in order to justify why a qualitative assessment is more suitable for the current study.

The following technologies used in the present study are part of the H2020 Nutri2Cycle[1] project, the focus of which is to close nutrient loops of nitrogen (N), phosphorus (P) and carbon (C) in agriculture.

2.2.1. Anaerobic digestion strategies for optimised nutrient and energy recovery from animal manure (farm scale anaerobic digestion)

Residues from agriculture may lead to odour and greenhouse gases (GHG) emissions. Farm scale anaerobic digestion technology produces renewable energy on-site and reduces GHG from manure storage and is a tool to increase energetic self-sufficiency and thus be less dependent on fluctuating energy market prices. In addition, it reduces the need for fossil fuels.

Biogas (main product) and digestate (subproduct) are the final products from the technology. The biogas consists mainly of CO_2 and CH_4, which can be combusted in a combined heat and power (CHP) installation, driving the generator that produces electricity. In addition, the farmer can also use the heat provided by the CHP. The digestate can be used as an organic fertiliser.

This technology was assessed regarding its use in agriculture in Belgium, where it has been developed and tested in the frame of the Nutri2Cycle project.

2.2.2. Precision fertilisation of maize using organic fertilisers (Precision fertilisation)

This technology combines precision fertilisation and manure application in a maize crop. To date, manure has been applied as a basal fertilisation, and P variability in the soil is not taken into consideration, which can lead to P accumulation and potential leaching. The technology proposes applying manure as a basal fertilisation based on P requirements established using precision farming tools. By using GPS georeferencing, precision fertilisation can adjust fertiliser application rates according to each specific location in the field. Nowadays, the process of variable-rate fertiliser application, considering the spatial distribution of nutrient content, the creation of fertiliser prescription maps and implementation in the field, is already being put into practice in many farms across Europe (Basso et al., 2016; Vatsanidou et al., 2017).

This technology was assessed regarding its use in agriculture in Germany, where it has been developed and tested in the frame of the Nutri2Cycle project..

2.2.3. Low-temperature ammonium-stripping using a vacuum (low-temperature stripping)

The aim of this technology is to remove nitrogen from the liquid matrix (manure or thin fraction from digestate). This is done by vacuum stripping and the ammonia is recovered in an absorption system. Absorption can take place using different acids (i.e. sulphuric, nitric or lactic acid), producing ammonia sulphate, ammonia nitrate or ammonia lactate respectively.

Ammonia salt solution can be considered a cleaned form of recuperated nitrogen (N). This ammonia, in the form of an ammonium sulphate, nitrate or lactate salt solution, can be reused as a fertiliser. While the added value of producing the cleaner ammonia water is not proven in the market and as the legislative framework has not been approved yet, the application of the technique will be limited.

This technology was assessed regarding its use in agriculture in Spain, where it has been developed and tested in the frame of the Nutri2Cycle project..

2.3. Prospective assessment of novel technologies for nitrogen recovery in agriculture

Social aspects can be firstly assessed applying S-LCA in novel technologies to evaluate potential aspects raised and their associated impacts, qualifying them qualified into positive or negative effects or changes compared to an already existing product, process or service (Burchi et al., 2013). The low adaptation of the solutions is one of the reasons for opting to undertake a prospective and qualitative S-LCA of the technologies.

2.3.1. Set of relevant indicators for the S-LCA of novel technologies for nutrient recovery in agriculture

It is important to highlight that most of the technologies that will be incorporated in agricultural systems, making them hard to evaluate as a standalone process due to the low adaptation in the society. Therefore, the prospective assessment undertaken in the present study assessed the potential social impacts due to the inclusion of these technologies considering the life cycle of the product system explored in the baseline.

[1] https://www.nutri2cycle.eu/

For a more comprehensive S-LCA method, a limited set of relevant, transparent and easily outlined indicators is required (Siebert et al., 2018). In the current study, the indicators selected prioritised the main issues concerning agriculture and nutrient recovery, both social and environmental indicators (midpoint indicators) with social consequences (endpoint indicators), where the technologies might have an impact. The proposed set of indicators and the assessment carried out aim to present in an easy format to end users and other stakeholders different areas that may be affected by technologies before these stakeholders introduce them into their product systems. For example, by introducing a new technology, stakeholders can contribute to making agriculture more financially attractive for young professionals, safer for workers and local communities, or for a sustainable society in which there is higher level of well-being in the environment, social and economic dimensions (Abad-Segura et al., 2020). The set of indicators is summarised in Table 2, which highlights their relevance for inclusion in the prospective assessment of the novel technologies for nutrient recovery in agriculture. It is important to note that caution should be exercised when carrying out an environmental LCA and a social LCA, using the proposed set of indicators, at the same time to avoid overlaps. It is necessary to clarify how the indicator can have social and environmental consequences or to eliminate the indicator from an assessment, whether environmental or social, as in Werker et al. (2019b).

2.3.2. Inventory and impact assessment method for qualitative and prospective assessment

Data for S-LCA can be collected from different sources, for instance, scientific publications, generic databases (i.e., PSILCA), interviews, and surveys (UNEP, 2020). For prospective assessments, data sources include expert interviews (Thonemann et al., 2020). The Excel questionnaire featuring the selected indicators was sent to experts in each technology due to the level of detail and the specificity of the assessment (Supplementary material S1). The experts selected in the present study were the researchers responsible for each technology in the Nutri2Cycle project. For each technology, at least two experts were responsible for the answers provided and another expert, the survey leader, was responsible for the review round, resulting in at least three experts for each technology.

The questionnaire was answered using a Likert scale (Albaum, 1997), taking into account the inclusion of a technology in a specific agricultural system. The Likert scale is used to measure attitude and, consist of a series of statements to which a respondent indicates a degree of agreement or disagreement using the following options: strongly agree, agree, neither agree nor disagree, disagree or strongly disagree. The proposed Likert scale was created following the psychometric scale proposed in Likert (1932), specifying the level of agreement with a statement (from totally agree to totally disagree). A detail definition of each potential response for the indicators, and the answers for each technology after two rounds of experts questioning for the indicators selected using the Likert scale are detailed in Supplementary material S3.

In the present study, an adapted version of the approach used in Franze and Ciroth (2011) was applied for the impact assessment, with an assessment method based on interpretation using a simple system with colours and statements. Through this method, results are readily understood and intuitive, and provide a quick overview of the potential impacts of the solutions. Considering the complexity of social phenomena and the difficulty of avoiding ordinal scales completely in S-LCA (Arvidsson, 2019), the scale in Table 3 was used in the impact assessment, ranging from 'potentially large beneficial effect' to 'potentially large harmful effect'. The indicators were not aggregated and the technologies were not ranked.

Qualitative aspects represent an action from which stakeholders experience the consequences of a product system (Siebert et al., 2018). In the present study, the assessment provided will guide end-users as to the nature of the technologies' potential effect, informing them of what potential effects the technologies may have. The qualitative information obtained from the questionnaires for the midpoint indicators underwent a review round owing to the importance of data triangulation in S-LCA (Ramirez et al., 2016), especially when qualitative data are used since there is no guarantee that the respondents have interpreted the potential effect in the same way (Fig. 2). The methodology applied in the review round is presented in the Supplementary material S4.

2.3.3. Comparative analysis using PSILCA

To compare the baseline and the potential changes brought about by the technologies, some indicators in the PSILCA database were selected as having the potential to be affected by the technologies in a potential scenario, with the technologies assessed in a specific analysis (Table 4). Given the difficulty of predicting quantitative data, the complexness of the indicators and the low societal adaptation of the technologies, it was decided to increase or decrease, where it was possible, the indicator's risk level by one level, according to the answers provided in Table 3 and Fig. 2, and keeping life cycle inventory as provided by PSILCA for each product system. Thus, for a potential benefit (PBE and HPBE as potential effects of the technology), the risk was reduced in one level in comparison to the risk established in the baseline, but for a potential harmful effect (PHE and HPHE as potential effects of the technology), the risk was increased in one level in comparison to the risk established in the baseline. It is important to note that if the risk is already in the lower boundary or upper boundary of the risk level, it is not possible to decrease or increase the risk, respectively, regardless the effect of the technology.

The baseline is assumed as to be a 'typical farm' in the respective country, and the technology scenario was the scenario considering the potential changes in risk due to inclusion of the technology, according to the answers in the questionnaire. The functional unit for both scenarios in the comparison was 1000 USD of a generic agricultural product output.

Ten indicators in PSILCA were associated to the midpoint indicators selected in the present study, meaning that potential benefits or harmful effects of the technologies could change the risks, increasing or lowering them, associated to each indicator in the countries and respective product systems assessed (Table 4). The indicator 'Presence of sufficient safety measures' can be improved with more training to use the technology more effectively. 'DALYs due to indoor and outdoor air and water pollution' was affected by the reduction (risk decreases) or increase (risk increasing) in GHG emissions. Risks in the 'Sector average, per month' can be reduced due to the inclusion of high-skilled workers required to operate the novel technologies. Risks in the 'rate of non-fatal accidents' that can be increased due to the insertion of new source of damage in the farm due to the novel technology. The technologies could promote a daily saving of labour, impacting beneficially, regarding H&S and well-being, in 'weekly hours of work per employee'. The risk in the 'level of industrial water use' can be increased or reduced according to the water demanded by the technology. The reduction of external sources of energy (i.e., due to biogas production) can reduce 'fossil fuel consumption'. Better management of manure (reducing ammonia emissions) can contribute to decrease the risk in the 'pollution level of the country', and the creation of new job positions would have a potential beneficial impact reducing risks in 'unemployment'. Finally, decreasing the dependence on the importation of mineral fertilizers can reduce the risk in the indicator 'Corruption'.

Table 2
Set of indicators for the S-LCA of novel technologies for nutrient recovery in agriculture.

Midpoint indicator	Indicator is addressed in...	Social endpoint indicators	Included because...
New job position	Hurst et al. (2005)	Unemployment Employment in agriculture	Green innovations introduced in rural areas are expected to create green jobs directly and indirectly Unemployment and underemployment in rural areas contribute to poverty and low wages The underestimation of unemployment in rural areas contributes to 'hidden employment' where workers give up searching for jobs or accept working for less time than they would like (Hurst et al., 2005)
High-level skills from workers	van Haaster et al. (2017)	Hours worked by high-skilled persons engaged High-skilled labour compensation	Innovative technologies that require high skills can be associated with decent wages, and safe work conditions, improving agriculture (Kim, 2018)
Training courses for workers	Urbancová & Depoo (2018)	Extent of staff training	Several farmers manage their farms by themselves, and training is not a priority in their daily working lives Employees in agricultural companies are aware of the need to learn and develop due to organisational, technological and social dynamics (Urbancová and Depoo, 2018)
More time in the daily work routine on the farm	Hurst et al. (2005)	Mean weekly hours worked by employed person by sex and economic activity Excessive working hours per country	Adequate working time is a crucial aspect of decent work, providing adequate periods of rest and recuperation Workers should have access to a minimum desirable number of hours of work to earn an adequate level of monthly remuneration, avoiding involuntary part-time employment and time-related underemployment (Hurst et al., 2005)
Healthy & safety (H&S) of workers regarding regulation for the technology and H&S of workers regarding new source of damage in the farm	van Haaster et al. (2017)	Existence of labour laws per country Cases of non-fatal occupational injury in agriculture Cases of fatal occupational injuries in agriculture	Agriculture involves dangerous work occupations due to the dangerous machinery used, unsafe electrical wiring and appliances, livestock-transmitted diseases, falls from heights, and exposure to toxic pesticides Governance or technical instruments intend to protect people and the environment using a technology that is adequately controlled, contributing to sustainable agriculture (Hurst et al., 2005; van Haaster et al., 2017)
Corruption (Potential avoidance of corruption in the substitution of impacting inputs)	PSILCA database (Maister et al., 2020)	Control of corruption (import of P fertilisers)	About 85% of P in agriculture comes from processing mined phosphate rock (Cordell et al., 2010), mainly in countries that have a high level of corruption, which both developed and developing countries have been ignoring (Drebee and Abdul-Razak, 2020). When avoiding the importation of P, due to the recovery of the nutrient, it has a potential to decrease non-domestic corruption in agricultural products value chain. An increasing body of literature has provided evidence of the environmental implications of corruption (social aspect).
Ammonia volatilisation (NH_3)	Sustainable Development Goal 2 (SDG 2) 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' (United Nations, 2022)	Mean population exposure to particulate matter (PM2.5)	Agriculture is a major contributor to ammonia emissions, but also has a high potential to mitigate them by implementing beneficial management practices. The exposure to ammonia volatilised (from a few hours to a few weeks) is associated with small but significant increases in cardiovascular disease-related mortality, and the size of this effect increases with longer-term exposure (Bittman et al., 2013).
Odour on the farm	Wohlenberg et al. (2020) Peters et al. (2014)	Psychological health effects per organisation, sector and country (number of accidents caused by physical or mental stress)	Living in proximity to large-scale livestock farms has been linked to symptoms of impaired mental health, as assessed by epidemiologic measures (Donham et al., 2007) There is evidence that persistent exposure to odours can have adverse effects, for instance, headaches, throat and eye irritation, nausea, sleeplessness, anxiety, stress, or even respiratory problems (D-NOSES consortium, 2019)
Water quality and water consumption	PSILCA database (Maister et al., 2020)	Use of abiotic and biotic resources and water per sector, area and country	Water pollution is a global challenge that has increased in both developed and developing countries, undermining economic growth as well as socio-environmental sustainability and health of billions of people (FAO, 2018) Water quality and water consumption are aligned to the Sustainable Development Goals (SDGs), especially SDG 6 'Ensure access to water and sanitation for all', and target 6.3 '... improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials' In the last century, water use has doubled the rate of population growth, and in the last 30 years, food production has increased by more than 100%, and agriculture has accounted for approximately 70% of global freshwater withdrawals (FAO, 2017).
Nitrate leaching	SDG 6 'Ensure availability and sustainable management of water and sanitation for all' (United Nations, 2022)	Pollution of water and groundwater per country	The Drinking Water Directive (EEC, 1991) defines 50 mg NO_3^-/L as the upper limit for nitrate concentration in water intended for human consumption, and concentrations above 25 mg NO_3^-/L are cause for concern Some public health studies have estimated elevated risks for subpopulations exposed to chronic levels of nitrate below the regulatory standard of 10 ppm nitrate-N, including increased risks of cancer and birth defects (Keeler et al., 2016)

(continued on next page)

Table 2 (*continued*)

Midpoint indicator	Indicator is addressed in...	Social endpoint indicators	Included because...
Phosphorus use (reduction of P importation contributing to reduce local communities' issues)	SDG 12 'Ensure sustainable consumption and production patterns' (United Nations, 2022)	Nutrient phosphate P_2O_5 (total) used P fertiliser importation (local communities affected)	Phosphorus supply disruptions may occur due, for example, to the concentration of production in a small number of countries, political instability, troubled labour and wage relations between workers and phosphate companies (Ridder et al., 2012) Cadmium accumulation in EU soils due to the use of P fertilisers made with contaminated rock can affect human health, not only causing environmental damage (Ridder et al., 2012) Some regions that are richest in phosphate reserves are also highly marginalised, with no political voice or economic opportunities
Reduction of external sources of energy	SDG 7 'Ensure access to affordable, reliable, sustainable and modern energy for all' (United Nations, 2022)	Electricity consumption in agriculture	The proper usage of renewable energy systems can achieve improvements in local employment, better health, job opportunities, job creation, consumer choice, better life standards, income development, demographic impacts, social bonds creation, and community development (Kumar 2020) Combining local renewable energy resources with the appropriate technology, self-supply and energy self-sufficiency are possible, generating stable prices and helping to achieve a sustainable model that would help repopulate rural areas (Kumar 2020)
Greenhouse gas emissions (GHG) (regarding health effects on people)	PSILCA database (Maister et al., 2020)	Burden of disease by country - risk contribution of air pollution (including GHG emissions) in DALYs (Disability-adjusted life year) for 'chronic obstructive pulmonary disease' Pollution levels by country	Negative impacts of climate change on crop productivity and livestock will become increasingly serious around the world, having impacts on productivity and consequently on food security (FAO, 2016) Agriculture, forestry and land-use change are responsible for around 20% of world's total GHG emissions (FAO, 2016) Climate change threatens society's health, but knowledge and policies linking the reduction of greenhouse gas emissions and potentially large effects on the population's health are not widespread (Haines et al., 2009) Climate-related health indicators are potentially useful for tracking the adverse public health effects of GHG emissions, enabling more focused interventions (Navi et al., 2017) Climate change has a huge potential to trigger or aggravate respiratory diseases (D'Amato et al., 2014)
Food production increasing and new knowledge and scientific purpose	SDG 2 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' (United Nations, 2022)	Food production index Expenditure on research and development (% of Gross Domestic Product - GDP)	Research and development and the proper dissemination of results to agriculturists are crucial to increase agricultural production and achieve food security (Ejeta, 2009)

Table 3
Qualitative assessment of social indicators using Likert scale parameters.

Level (Likert scale)	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Impact assessment	High potential of beneficial effect (HPBE)	Potential beneficial effect (PBE)	Indifferent effect (IE)	Potential harmful effect (PHE)	High potential of harmful effect (HPHE)

3. Results

3.1. Impact assessment

3.1.1. Social impact assessment of the baseline and identification of hotspots

This section addresses potential social hotspots in the agricultural value chain in Belgium, Germany, and Spain (Fig. 3; Supplementary material S2), with indicators assessed according to their impact within the value chain and their respective risk in the subcategories used in PSILCA. The indicators within each subcategory can be checked in Maister et al. (2020). The total impact for the baseline, in med risk hours, using PSILCA, was 10.14 in Belgium, 11.71 in Germany and 12.66 in Spain, representing the estimated total numbers of hours of risk to produce 1 USD output. It is important to bear in mind that for the subcategory 'contribution of the sector to economic development' (ECO) this is a positive impact, representing an opportunity of 0.033, 0.027 and 0.039 med

Table 4
Indicators from PSILCA database affected by the technologies for nutrient recovery and their association to the midpoint indicators selected in this study.

Stakeholder	Indicator in PSILCA	Midpoint indicator in the present study
Workers	Presence of sufficient safety measures	Training courses for workers
	DALYs due to indoor and outdoor air and water pollution	Greenhouse gas emissions (GHG) (regarding health effects on people)
	Sector average wage, per month	High-level skills from workers
	Rate of non-fatal accidents at workplace	H&S of workers regarding new source of damage in the farm
	Weekly hours of work per employee	More time in the daily work routine on the farm
Local community	Extraction of fossil fuels	Reduction of external sources of energy
	Level of industrial water use (related to total withdrawal)	Water quality and water consumption
	Pollution level of the country	Ammonia volatilisation (NH_3)
	Unemployment rate in the country	New job positions
Value chain actors	Corruption	Corruption (Potential avoidance of corruption in the substitution of impacting inputs)

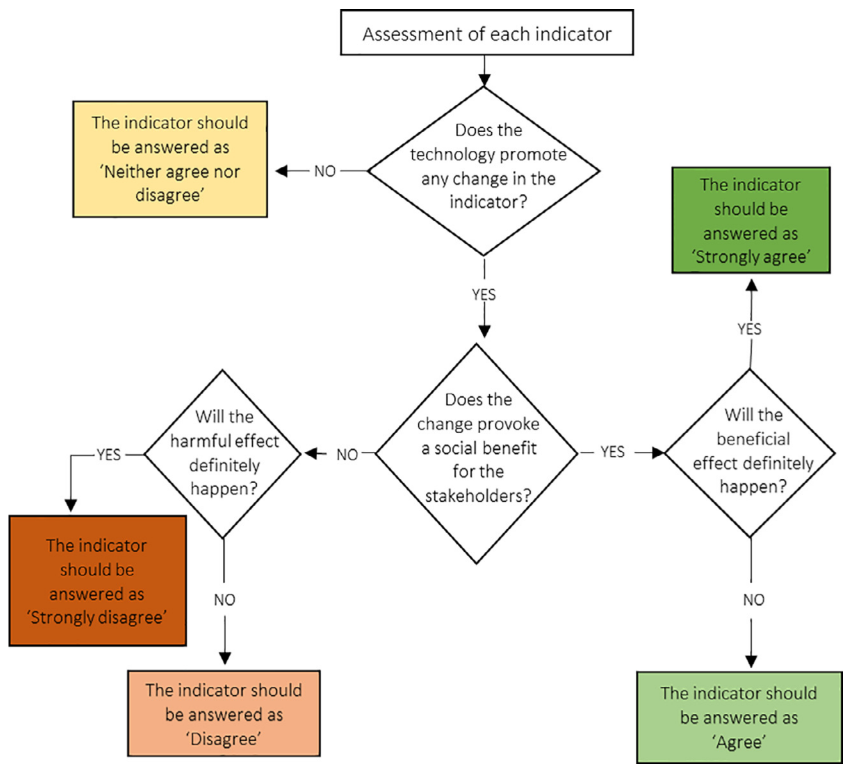

Fig. 2. Decision tree for building the social Life Cycle Inventory (S-LCI) through the identification of potential social impacts from solutions for nutrient recovery in agriculture and livestock.

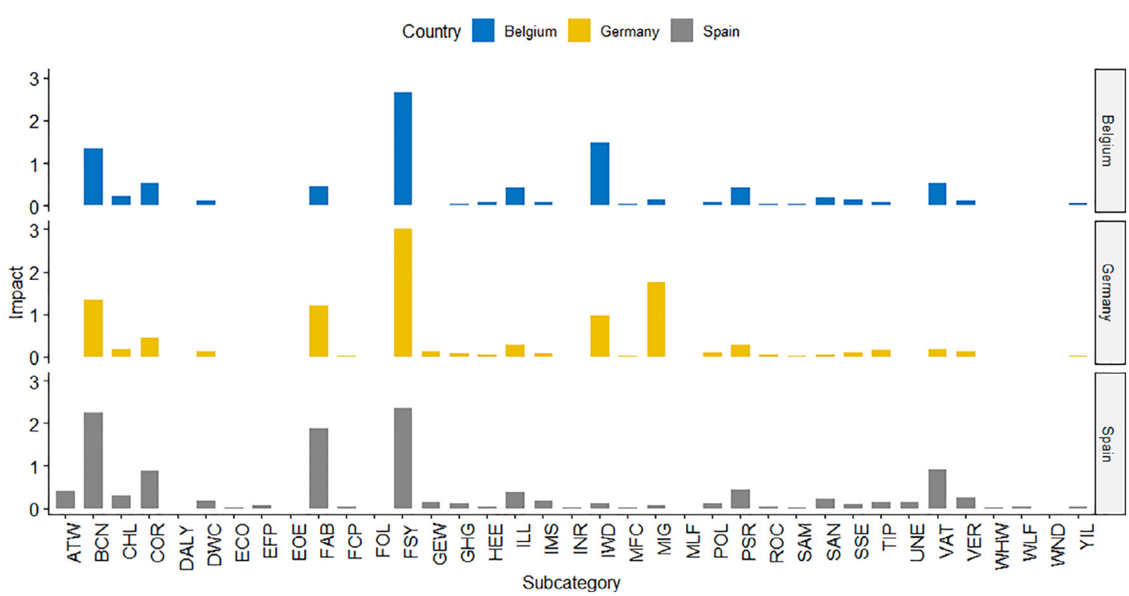

Fig. 3. Impact assessment (med risk hours[a]) of the baseline in agriculture in Belgium, Germany and Spain considering PSILCA database subcategories.
Legend: ATW: accidents at work, BCN: biomass consumption, CHL: child labour, COR: public sector corruption, DALY: disability-adjusted life years due to indoor and outdoor air and water pollution, DWC: drinking water coverage, ECO: contribution of the sector to economic development, EFP: embodied footprints, EOE: expenditures on education, FAB: freedom of association and collective bargaining, FCP: fair competition, FOL: forced labour, FSY: fair salary, GEW: gender wage gap, GHG: greenhouse gases footprints, HEE: health expenditure, ILL: illiteracy, IMS: international migrant stock, INR: indigenous rights, IWD: industrial water depletion, MFC: minerals and fossil fuel consumption, MIG: migration, MLF: men in the sectoral labour force, POL: pollution, PSR: promoting social responsibility, ROC: risk of conflicts, SAM: safety measures, SAN: sanitation coverage, SSE: social security expenditures, TIP: trafficking in persons, UNE: unemployment, VAT: value added (total), VER: violations of employment laws and regulations, WHW: weekly hours of work per employee, WLF: women in the sectoral labour force, WND: workers affected by natural disasters, YIL: youth illiteracy
[a]Note that the impact produced in the indicator 'contribution of the sector to economic development' represents an opportunity, therefore, a positive impact.

risk hours for the sectors, respectively in Belgium, Germany and Spain.

The baseline assessment showed that, considering PSILCA indicators and subcategories, the greater impacts in the value chain of agriculture and potential hotspots in the systems were found in 'fair salary (FSY)' for the three countries assessed. Other important subcategories with large impacts are 'biomass consumption (BCN)', 'industrial water depletion' (IWD), 'value added (total) (VAT)', 'public sector corruption' (COR), 'freedom of association and collective bargaining (FAB)', and 'migration (MIG)'. Therefore, these are the subcategories should be improved in order to contribute to social sustainability in the agricultural sector, i.e. the hotspots in light of the PSILCA results. A detailed explanation for the subcategories with the greatest impacts follows.

'Fair salary' (FSY) is assessed in consideration of the living wage. A living wage is defined as the income needed for a decent living, thus the higher the living wage, the higher the minimum and sector average wages have to be in order to reduce social risks (Maister et al., 2020). In Belgium and Germany, the living wage is more than a thousand dollars per person per month, representing a very high risk, while for Spain it is between 576 and 768 dollars per person per month, representing a high risk. Regarding the sector's average wage, agriculture was found to be a very low risk activity in Germany and Spain, and low risk in Belgium, although agriculture is considered a low-paid sector. It is important to note risk levels for living wage are defined after a combination with the minimum, since the concept of living wage is not necessarily clear, and it is assumed that a very low minimum wage aggravates living conditions in general (Maister et al., 2020).

The 'biomass consumption' (BCN) is assessed as the area used to extract biomass (Maister et al., 2020). Biomass consumption higher than 800 t/km^2 is considered a very high risk. For Belgium and Germany, biomass consumption was, respectively, 2082 and 1375 t/km^2 respectively, and for Spain it was 433 t/km^2, representing a medium risk. The risks were established considering average values across all countries included in the PSILCA database.

'Industrial water depletion' (IWD) was an issue in the agricultural sector in Germany and Belgium, being attributed a very high risk for this subcategory. The risk is related to the indicators addressing water consumed being higher than 40% of the total withdrawal and more than 13% of the total renewable water resources in those countries. In Spain, the indicators were classified as low and medium risk respectively.

The indicator 'embodied value-added total' is part of the subcategory 'embodied footprints' (EFP), and it is the result of the difference between inputs (i.e., energy and materials) and outputs (i.e., products and coproducts) of the process divided by the gross output of the sector, obtained from EORA. The indicator embodied value-added total is calculated per 1 dollar of output (Maister et al., 2020). Different processes are higher contributors for very high risks in the agricultural value chain. In Belgium, it was the production of chemicals and chemical products, such as chemical fertilisers used in agriculture. In Germany, was due to the 'wholesale trade, except of motor vehicles and motorcycles' process that includes wholesale trade on its own or on a fee or contract basis related to domestic wholesale trade, as well as international import and export. In Spain, the manufacture of prepared feeds for farm animals represents a very high risk in the indicator.

'Public sector corruption' (COR) is a subcategory mainly influenced by the acquisition of imported products in the countries assessed in the present study. The subcategory presented indicators with a very high risk in the Belgian and Spanish agricultural chains, mainly due to agricultural imports from Argentina such as fruits and nuts, and the cultivation of vegetables and other crops. In Germany, it was influenced by mined products imported from China and India, and agricultural products from Argentina. Thus, the greatest impacts were related to non-domestic processes that are intrinsic to the product chain. The same happens for other indicators, for instance the risk of contributing to child labour and youth illiteracy due to agricultural products imported from India, although those processes make a small contribution to the product chains assessed in the current study.

The subcategory 'Freedom of association and collective bargaining' (FAB) has indicators with a very high risk in agriculture in Germany and Spain due to the indicator 'trade union density', but not in agriculture in Belgium (very low risk). This indicator represents the number of employees who are members of an organised union as a percentage of the total number of employees (Maister et al., 2020). A very high risk is related to the situation where fewer than 20% of the employees are members of a trade union, and a very low risk is when this value is above than 80%.

Finally, impacts in 'migration' (MIG) have a high value in Germany since the migration rate in the sector is above 15‰ (per mille). Germany is a country that is very open to receiving migrants, which means that issues related to religion, race or discrimination may represent risks if not addressed properly (Maister et al., 2020). In Belgium, the sector has high and medium risk, respectively, and in Spain there is a medium risk.

3.1.2. Social impact assessment of technologies for nutrient recovery considering experts knowledge

The technologies were prospectively evaluated, bearing in mind that they can vary greatly according to the context (country/farm) in which they are applied or the baseline with which they are compared. In the present study, social impacts were assessed considering where the technology is developed and the midpoint indicators selected in Table 1, and final results after the two rounds of questioning is presented in Fig. 4. It is important to highlight that the social assessment provided in this section has no evidence yet due to the low level of adaptation of the technologies, thus, they were assessed as a potential effect.

Farm-scale anaerobic digestion' technology scored 18% in HPBE, 41% in PBE, 35% in IE, 6% in PHE and 0% in HPHE. A technician is recommended for monitoring the biogas installation, and a professional maintenance engineer could be helpful with managing the technology. Although an additional activity is introduced into the system, it is not expected to take much time to do it, thus no extra time of work is necessary and working time could potentially be saved. The biogas produced is inflammable, which can create a harmful effect, making the observation of strict safety rules essential when cleaning the reactor. However, it is expected that with prior adequate training, the risk of damage can be minimised. Since agroresidues will no longer be stored, it is expected a reduction in odour, which is beneficial for workers and to the local community. The production of renewable energy has a potential to contribute to the reduction of fossil-based energy requirements, consequently contributing to decrease GHG emissions.

The use of organic fertilisers in the technology 'precision fertilisation' had 18% HPBE, 35% PBE, 24% IE, 12% PHE and 12% HPHE. This technology has the possibility to create a new market, requiring more human resources. In addition, since the use of organic materials as fertilisers is more complex than mineral fertilisers, it is recommended that high-skilled workers to manage this technology, which can be achieved by encouraging more training for workers and hiring skilled labour. Currently, regulations on the use of fertilisers are general and do not promote the use of organic materials, thus suggesting the use of organic fertilisers might press policymakers to create new more specific regulations. In addition, the use of organic materials increases the soil organic matter content, which can have a direct impact on water retention and the potential reduction of water consumption for irrigation. However, it is

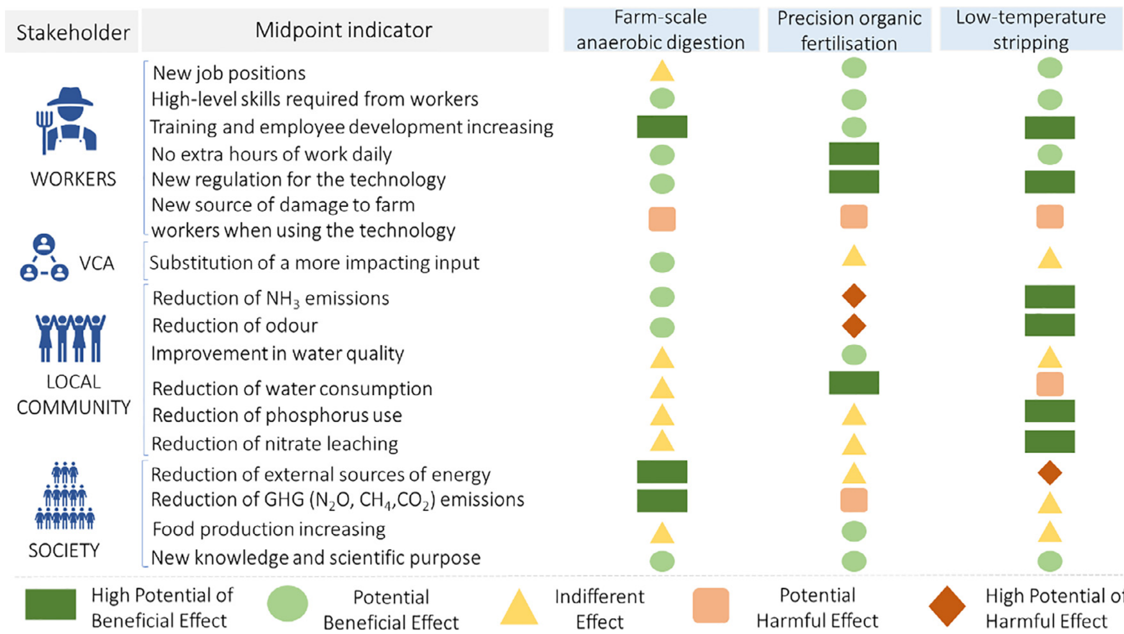

Fig. 4. Social assessment of the potential impacts of solutions used to recover nutrients from agricultural and livestock practices.
Legend: VCA = value chain actors; GHG = Greenhouse gas; N_2O = nitrous oxide; CH_4 = methane; NH_3 = ammonia; CO_2 = carbon dioxide.

expected that the technology could contribute to ammonia volatilisation increasing the odour for workers and the local community, although mitigation techniques are available, and has the potential to increase GHG emissions due to the use of organic fertilisers.

'Low-temperature ammonium-stripping' scored 35% in HPBE, 24% PBE, 24% IE, 12% PHE and 6% in HPHE. It is expected that new job positions will be created since this technology will need technicians for installation and maintenance. Training farmers to operate the technology is important, and technicians must be trained to maintain the plant. This technology was developed to work automatically and remotely controlled, requiring only a brief supervision, which can save some work time, but it is still recommended that a technician operates and checks the proper functioning of the plant. When the technology is correctly used, no air pollution is expected from the reaction of ammonia and sulphur dioxide, but this can be considered a potential source of damage to workers. Proper handling of acidic or basic potential of hydrogen (pH) substances will prevent personal injury. The main aim of this technology is the recovery of ammonia from livestock manure, avoiding manure storage in open pits for long periods, and uncontrolled ammonia emission to atmosphere, consequently reducing odour on the farm.

A summary of the potential social benefits and harmful impacts of the novel technologies for nutrient recovery in agriculture is provided in Table 5. The detailed assessment of the midpoint indicators for the technologies is presented in SM 3.

3.1.3. Comparative analysis: baseline x technology

The risk level in the baseline and technologies scenarios (represented in Table 6 by their respective countries) are shown in Table 6. The required training to work with the technologies represents an improvement of 'presence of sufficient safety measures', thus the risk levels from the technologies in Belgium and Germany were reduced by one level (from low risk to very low risk). There is no data for Spain regarding the indicator. The risk for 'DALYs due to indoor and outdoor air and water pollution' has been raised by one level (from 'very low' to 'low') in Germany due to the potential emission of NH_3 and odour from the use of organic fertilisers. Since the risks 'rate of non-fatal accidents at workplace' and 'extraction of fossil fuels' are already 'very low' for the three countries, no changes were made. As far as 'weekly hours of work per employee' is concerned, the risks were reduced by one level (from 'medium' to 'low') in Belgium and Germany, as the technologies have the potential to save some time during daily work. No changes were attributed to Spain because the lower risk level for this indicator is 'low'. Risk for 'level of industrial water use (related to total withdrawal)' indicator was reduced in Germany (from 'low' to 'very low' risk) since the technology has the potential to reduce water consumption in the crop, but it has been raised in Spain as the technology will consume water, potentially increasing system's water consumption. The risks in 'pollution level of the country' were reduced in Belgium (from 'medium' to 'low') and in Spain (from 'low' to 'very low') since both technologies have the potential to reduce NH_3 emissions. For the indicator 'unemployment rate in the country', the risk was reduced in Germany and Spain since there is potential job positions creation due to the inclusion of the novel technology in the agricultural system. No changes have been made in the indicator 'Corruption' since most of impacts are non-domestic, therefore they low potential to be affected by the technology, although the overall product system impact can be reduced avoiding imports from countries with high level of corruption.

The overall impact of assuming including the technology in each scenario reduced by 0.02%, 0.04% and 0.06%, respectively, in Belgium, Germany, and Spain. The small differences found, from the baseline were due to the potential changes induced by the technologies not affecting the impact categories that have greatest impacts (see Section 3.1.1). Furthermore, only a few categories used in PSILCA were able to show potential changes brought about by the technologies (Table 7) (Supplementary material S4). Other indicators that could be affected by the technologies are presented in Supplementary material S6.

4. Discussion

4.1. Interpretation: complementary assessment

Although scenario storylines attempt to show the different facets of the world, they do not fully reflect the true situa-

Table 5
Summary of potential social benefits and harmful impacts of the novel technologies for nutrient recovery in agriculture.

Farm scale anaerobic digestion	Precision organic fertilisation	Low-temperature stripping
Examples of potential beneficial impacts		
It is recommended a technician (with high level skills) for biogas installation	It can contribute to the creation of a new market of organic fertilizers	It is recommend technicians (with high level skills) for installation and maintenance of the technology
It is expected that a potential working time could be saved	It is recommended workers with higher skills to operate the technology	Some working time saved
It is expected reduction in odour due to lower ammonia emissions	It has the potential to contribute to the production of organic fertilisers, and potentially new and more specialised regulations	No air pollution from the technology is expected
Production of renewable energy as biogas possibly contributing to reduce fossil fuels consumption	It has the potential to decrease in water consumption in the crop	A better management of the manure has a potential to reduce the odour in the farm and surroundings
	Examples of harmful impacts	
Biogas produced is inflammable which is a potential risk to workers and the local community	It has the potential to Contribute to ammonia volatilisation and GHG emissions, which have an impact on people's health	Energy consumed in the technology might be a problem, increasing energy demand in the system

Table 6
Indicators from PSILCA which have the potential to be affected by the technologies, and their risk level in the baseline (risks from PSILCA) and technology scenario (risks according experts' responses to the questionnaires).

Stakeholder	Indicator in PSILCA	Risk B Belgium	T	B Germany	T	B Spain	T
Workers	Presence of sufficient safety measures.	*LR*	*VLR*	*LR*	*VLR*	ND	ND
	DALYs[a] due to indoor and outdoor air and water pollution.	VLR	VLR	*VLR*	*LR*	VLR	VLR
	Sector average wage, per month.	LR	LR	VLR	VLR	VLR	VLR
	Rate of non-fatal accidents at workplace.	VLR	VLR	VLR	VLR	LR	LR
	Weekly hours of work per employee.	*MR*	*LR*	*MR*	*LR*	LR	LR
Local community	Extraction of fossil fuels	VLR	VLR	VLR	VLR	VLR	VLR
	Level of industrial water use (related to total withdrawal)	VHR	VHR	*LR*	*VLR*	*LR*	*MR*
	Pollution level of the country	*MR*	*LR*	ND	ND	*LR*	*VLR*
	Unemployment rate in the country	LR	LR	*LR*	*VLR*	*HR*	*MR*
Value chain actors	Corruption	LR	LR	LR	LR	HR	HR

[a] Disability Adjusted Life Years.

Table 7
Comparative analysis for the S-LCA of novel technologies for nutrient recovery in agriculture considering U$ 1000 output, highlighting impact categories whose results can be changed by the technology.

Indicator		**Typical farm in Belgium**		**Typical farm in Germany**			**Typical farm in Spain**	
		B	*T*	*B*	*T*		*B*	*T*
DALYs due to indoor and outdoor air and water pollution	6.2		6.2	1.8	2.2		10.2	10.2
Industrial water depletion	1497.8		1497.8	976.2	975.8		140.2	143.9
Pollution	111.6		110.5	134.9	134.9		149.7	149.4
Safety measures	53.4		53.3	40.9	40.6		50.4	50.4
Unemployment	10.1		10.1	7.9	7.5		163.0	126.1
Weekly hours of work per employee	28.9		27.8	31.2	27.6		25.0	25.0
TOTAL IMPACT[*]	10,144.8		10,142.5	11,655.6	11,651.2	12,638.6		12,630.9

Legend: *B* = baseline, *T*= technology.
[*] Total impact considering all impact categories.

tion. However, they do achieve a simulation of reality, showing potential situations, and communicate might happen in future (Rounsevell et al., 2010). This section highlights indicators that are covered by the PSILCA database and that have the potential to be affected by the novel technologies (Table 4). Other relevant indicators are presented in the Supplementary material S5.

The 'presence of sufficient safety measures', estimated in PSILCA, was attributed by the 'Severe injury reports 2019′ document from the United States. The indicator measures the number of accidents, safety and health incidents per 10,000 employees in the sector. In 2020 in Germany, there were an estimated 582,000 workers in agriculture (Statista, 2021), around 300,000 (Ceicdata, 2021) in Belgium and 765,000 in Spain (Statista, 2021). Thus, to go from 'low' to 'very low' risk, a total of 28.5, 1.47 and 37.5 accidents and incidents (per 100,000 employees) have to be avoided in German, Belgian and Spanish agricultural sectors respectively. According to the ILO (2021), insufficient labour inspections, a lack of hazard training are causes of accidents and incidents in agriculture. Thus, promoting training and development for workers and creating new regulations are essential if accidents and incidents in agriculture are to be avoided following the inclusion of the novel technologies.

'DALYs due to indoor and outdoor air and water pollution' is the most suitable indicator, in PSILCA, for assessing potential social effects with regard to the reduction of emissions in agriculture. However, in this case, the two sources of air and water pollution are accounted for together in the same DALY and the data used were from 2004. DALYs were updated in 2016 (WHO, 2016), and the data for 'ambient air pollution' are divided into lower respiratory infections, tracheal, bronchial and lung cancers, cataracts, ischaemic heart disease, stroke and chronic obstructive pulmonary disease. 'Lower respiratory infections' include GHG emissions, and therefore are related to agricultural emissions (Lee, 2010). According to WHO (2016), the DALYs (per 1000 population) due to 'lower respiratory infections' are 0.78 (very low risk), 0.44 (very low risk) and 0.30 (very low risk) in Belgium, Germany, and Spain, respectively, representing a very low risk in PSILCA. Unfortunately, data are not provided for workers or specific industry sectors, which would be useful for estimating how much this indicator is affected by agricultural practices and potential effects due to the inclusion of novel technologies in agriculture.

According to Salary Explorer (2021) and the risk scale estimated in PSILCA (Maister et al., 2020), the average wage in the agricultural sector in Belgium is 3880 €/month but ranges from 1890 to 8930 €/month. In Germany, it is 2290 euros, ranging from 960 to 5670 €/month. In Spain, this figure is 1710 euros, ranging from 830 to 3940 €/month. The risks in PSILCA (Maister et al., 2020) are attributed considering the ratio between average salary and living wage, or average salary and minimum wage. The minimum wage (in euros) in Belgium, Germany and Spain are respectively, 1626, 1585 and 1126 (Country economy, 2021). Thus, the risks for salaries (lowest, average and highest salaries) in agriculture in Belgium are, respectively, high, low and very low. In Germany, the risks are, respectively, very high, high and very low. In Spain, the risks are very high, high and very low. No changes were attributed to this indicator, but if in a near-future it becomes mandatory include technologies to reduce impacts in agriculture, more technicians will be required to deal with the technology. Thus, the average salary in the sector has the potential to be increased, attracting more young and highly skilled professionals to the sector, but the lower salaries, responsible for the higher risks, may not change. Another important point is related to the definition of stakeholders. In the current study as well as in PSILCA, workers fall within the same stakeholder category, but if agricultural workers are divided into different categories (i.e. farm owners, technicians, farm managers, agricultural workers in general) different impacts and hotspots could be addressed. Thus, it is essential to provide ranges for this indicator; however, it is not clear how these should be grouped in a final indicator without losing the potential discrepancies identified.

In 2018, the total number of non-fatal accidents in agriculture in Belgium, Germany and Spain were 398, 47,652 and 29,378, respectively (Eurostat, 2021). In Europe, most of them (66.5%) (Eurostat, 2021) occurred on the farm or in the forest zone, and 28.3% were due to agricultural work or work with live animals. Regarding the specific physical activity that was carried at the exact time of the accident, the activity 'handling of objects' represented 27% of non-fatal accidents in Spain (Eurostat, 2021). This activity could be affected by the inclusion of the novel technologies, either reducing or increasing this number. An increase could be due to the handling of acids or new equipment introduced with the technologies, but with good training this number could be the same or decrease over time. Therefore, for this indicator, more time is needed for a better evaluation, according to the level of implementation of the technologies in agriculture and the data provided. A positive point is the level of specificity in the Eurostat database, although it would be of greater interest if the data for arable and livestock systems were split.

With regards to working time, labour-saving technologies (i.e. precision fertilisation and adoption of other machinery) are in demand due to the complex, highly variable environment in agriculture, and these can led to increased productivity and quality of agricultural output, and reduced dependence on labour, as well as improved environmental control (Gallardo and Sauer 2018). For instance, the time, effort and energy expended in a small family homestead differs significantly from that on a large commercial livestock farm. In farms that are a commercial concern, farm owners are more cautious of employees and interns' work. Thus, full-time employees work a little under 35 h and part-time workers typically work around 20 h a week. However, farmers who own their own businesses usually work about 44 h a week (Bureau of Labor Statistics, 2021). (Umstätter et al., 2016) claim that the working hours per person have tended to remain stable with technological progress since the resulting reduction in working time is being used for other activities. Thus, it is hard to make predictions for the indicator on working time since it depends greatly on the farm and work conditions.

It could be argued that there is some overlap between social and environmental indicators; however, their inclusion is deemed important in a social assessment because it results in greater focus on the social consequences of environmental damage, while in environmental LCA the focus is on quantifying the damage.

The exploitation and destruction of natural resources can directly affect local communities whose livelihoods and economies are based on fossil fuels, biomass and ores, for instance (Maister et al., 2020). In 2018, Spain consumed 1033.5E03 tonnes of nitrogen fertiliser (Eurostat, 2021), and 23.8% of imports of mixed mineral or chemical fertilisers came from Morocco (OEC, 2021), where there is evidence that rights to health of workers and local communities are being overlooked (Switzer, 2019). In Belgium, 29% of mixed mineral or chemical fertilisers were imported from Russia, which suffers from a depletion in the source of phosphate fertilisers (Saritas and Kuzminov, 2017). The precise application of nitrogen, the removal of nitrogen pollution from the environment and the use of organic fertilisers will help reduce the consumption of mineral fertilisers, decreasing the pressure on natural resources and specific local communities.

A controversial indicator is the indicator related to water. Results provided by PSILCA can contradict those from other sources. In Belgium, the agricultural sector consumes 1.12% of total water withdrawal and 0.24% of total renewable water resources (FAO 2021), both representing a very low impact, although PSILCA identifies a very high risk for both indicators. In Germany, the same divergence was found when comparing PSILCA risk levels and AQUASTAT data (FAO, 2021). A very high risk for agricultural water withdrawal (related to total renewable water resources) was identified in PSILCA, but in AQUASTAT this value was 0.25%, which represents a very low risk; there was also a low risk for agricultural water withdrawal (related total water withdrawal), while in AQUASTAT this value was 1.4%, which was a very low risk. For Spain, the opposite was found, with lower risks in PSILCA and higher risks in AQUASTAT. Spain has a very high risk related to agricultural water withdrawal both related to total withdrawal (65%) and to total renewable water resources (18%), although in PSILCA it is identified as a low and medium risk respectively. In addition, the AWARE method (Boulay et al., 2018), used in environmental LCAs to assess water scarcity, shows small characterisation factors (for irrigation) for Belgium (2.208) and Germany (1.778), representing a potential low impact, and a high value for Spain (80.760), representing a potential high impact.

The 'pollution level of the country' assesses the overall level of pollution in a country through an index, based on visitors' perceptions, and ranges from 0 to 100, with 100 being the worst result. The index for Belgium and Spain in 2019 was 49.89 and 39.36

respectively (Numbeo, 2019). No data are attributed to Germany in PSILCA, although there is a value of 28.01 in Numbeo (2019). According to Maister et al. (2020), the indicator is suitable for assessing safe and healthy living conditions of local communities. Therefore, since other types of pollution such as noise and waste disposal are included, the inclusion of novel technologies may have the potential to change peoples' perception regarding of pollution. However, to better assess this indicator, it should be assessed in a rural area or in a local community near an agricultural area.

Special attention should be paid to the indicator 'Unemployment rate'. Rotz et al. (2019) highlight that the rapid advance of agricultural technologies has led to different predictions about the future of labour and rurality. For some experts, agricultural technologies can lead to the exploitation of marginalised and racialised labourers by landowners, governments and corporations, resulting in social, economic, and racial inequities in labour, skills development and rural spatiality. However, it has suggested that novel technologies can positively contribute to creating new workplace opportunities in rural communities. Again, the way in which the technology will impact this indicator should be assessed in a specific analysis because it will depend on working conditions applied. For instance, a company could train an employee, not necessarily with high-level skills, to work with the technology or they can hire another worker with experience in that technology. More research and greater maturity of the technologies are needed before a change in the indicator can be confirmed.

Corruption can be measured by the Corruption Perceptions Index (CPI) that ranks countries from 0 to 100, with 100 being the least corrupt (Nedelciu et al., 2020). Usually, one product life cycle affects several countries, and several of the P fertiliser importers into Spain (Jordan, CPI 49) and Belgium (Morocco, CPI 40) have a very high risk of corruption, measured by the Corruption Perceptions Index (CPI) (World Bank, 2019), socially affecting the agricultural products. The situation is similar to Germany, with more than 70% of P fertilisers imported from Israel, which has a CPI of 60; although it is a high CPI, it is similar index to, for instance, Spain (62) and Portugal (61). Improving nutrient efficiency by increasing the use of organic fertilisers and reducing losses will contribute to a decrease in the import of mineral fertilisers, consequently reducing social impacts in the value chain, but it does not solve the problem corruption.

It is important to highlight that the use of agricultural product systems in PSILCA certainly influences the results, especially related to the flows considered in the selected product system. PSILCA still takes an environmental studies approach and focuses on negative impacts (or risks). In addition, in PSILCA some social indicators can also be environmental indicators, for instance, 'extraction of biomass', 'level of industrial water' and 'embodied CO_2 footprint'; therefore, care should be taken in sustainability assessments to avoid double counting of impacts. It is evident that the database will evolve when the data are available, thus, in a near future it is expected that more indicators to assess opportunities will be included in the database.

4.2. The diverse use of PSILCA in S-LCA

In the present study, the PSILCA database was used in the S-LCA. However, the representativeness of the data represents a challenging issue for the social LCI in PSILCA due to data availability (Kono et al., 2018). Even though the database covers almost 15,000 different sectors in 189 countries, for a more specific situation in a sector, a complementary assessment is necessary. In the current study, the focus was on strategies for reducing nutrient losses in agriculture, but only a few indicators were available to assess those impacts, making necessary to undertake a complementary assessment to contextualise the results provided.

Werker et al. (2019b) assessed the social impacts on working conditions of a novel technology hydrogen production by advanced alkaline water electrolysis (AEL) from a life cycle perspective when installed in Germany, Austria and Spain. They used a mixed methodology, PSILCA version 2.0, and complemented and compared it with raw data and a qualitative literature analysis. Although they acknowledge that a greater number of indicators and detailed results are provided, PSILCA excludes important segments of society, such as informal workers, which are relevant for agricultural systems. In addition, the concept of medium risk hours in PSILCA is difficult to understand.

In the current study, PSILCA was used to build a baseline scenario and identify hotspots.Hannouf and Asefa (2018) used the database to evaluate the social performance of background processes in a high-density polyethylene production. With PSILCA, they were able to address the social hotspots areas that require a greater focus from suppliers. In the case of the novel technologies assessed here, hotspots and the potential benefits or harmful effects added into the agricultural system could be identified.

4.3. Prospective assessments in social studies, including S-LCA

Prospective assessments in S-LCA are under-investigated due to the difficulty of predicting social impacts since it involves many variables. According to van Haaster et al. (2017), social indicators are difficult to predict since they are time, region and circumstance specific and management dependent.

Haines et al. (2009) uses the DALYs to measure healthy years saved due to the mitigation measures in four sectors (household energy, transport, food and agriculture, and electricity generation) using a 'comparative risk assessment' (Wilkinson et al., 2007) to model the potential effects. They recognised that the model has limitations, but they provide important comparative evidence of the possible health effects expected from the adoption of mitigation policies.

In addition, van Haaster et al. (2017) uses S-LCA to develop a framework to assess aspects related to well-being that are potentially affected by novel technologies. The study has a future-oriented approach relying on the construction of scenarios. They selected 11 indicators, including knowledge-intensive jobs and total employment, but they assessed these two indicators quantitatively, unlike the present study. They also address those uncertainties are commonly found in prospective assessments, especially when it comes to the definition of baseline scenarios, which is also highlighted in the current work.

Although the methodologies showed have many limitations, the identification of indicators that could be temporally consistent and cover relevant hotspots, and consistent models or methods to measure or estimate them, are essential to be improved for future research on aggregating prospective and quantitative assessments in S-LCA. Those methods and models and social mechanisms are also relevant for S-LCA using impact pathways[2] (UNEP, 2020) as impact assessment approach.

5. Conclusions

The aim of the present study was to select and test indicators in order to perform an S-LCA of novel technologies to be applied in agriculture, undertaking comparison with a baseline in agriculture in Belgium, Germany and Spain. A set of indicators of this kind enables the assessment of social hotspots and opportunities related to novel technologies applied in agriculture to recover nutrients and improve of nutrient efficiency.

[2] Translation of social activity/stressor into a social damage (Maister et al., 2020).

Through the questionnaire and expert knowledge, examples of potential impacts of the technologies included the need for highly skilled workers, attracting a highly qualified labour force to agriculture, increasing training and employee development, improving the efficiency of the technologies, in the case of some of them, helping to reduce accidents at work, and the need for new regulations to deal with organic fertilisers more effectively. In addition, novel ways to properly dealing with manure can involve a reduction in odour and other gases for local community and can also contribute to new knowledge and scientific research to improve agriculture. Other indicators, such as new jobs or a reduction in extra hours at the farms, were revealed to be site-dependent and would vary depending on the company or farmer behaviour. However, the inclusion of novel technologies may introduce new sources of damage, for instance, when using acids or working with heavy machinery, although these risks are controllable. Experts were cautious about the potential effects related to N and P emissions since emissions vary according to the conditions in which fertilisers are applied, making a potential effect harder to define.

Using the PSILCA database for the comparative analysis, small difference was seen between the baseline and the potential scenario with the technology included just increasing and decreasing risks of the indicators. A consistent explanation is the fact that the PSILCA is insufficiently sensitive to small changes because it is too generic to show benefits offered by the technologies. Another point is that the indicators for which the technologies have potential to bring about change did not show a high impact in the baseline.

Qualitative assessments for prospective studies in S-LCA may be a starting point for predicting the potential benefits and harmful effects of novel technologies. For future work, also depending on the maturity of the technologies, wherever possible a full S-LCA of technology, either standalone or in the context in which is applied, should be undertaken, in order to provide quantitative ranges for each indicator. The initial screening provided by experts in the technologies should be confirmed using quantitative data for each type of technology and potential scenarios.

Funding

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie [grant number: 713679].

Supplementary material

Supplementary material can be accessed in the following link: https://1drv.ms/x/s!AiM0z1iKRPTCg9BaZ6Bo8xTK0UgNTA?e=ZsoqaD

Declaration of Competing Interest

None of the authors are aware of any conflicts of interest.

Acknowledgment

We thank the project Nutri2cycle [grant number: 773682] for the full support during this work and the CERCA Programme/Generalitat de Catalunya.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2022.01.025.

References

Abad-Segura, E., Morales, M.E., Cortés-García, F.J., Belmonte-Ureña, L.J., 2020. Industrial processes management for a sustainable society: global research analysis. Processes 8. doi:10.3390/PR8050631.

Albaum, G., 1997. The Likert scale revisited: an alternate version. Int. J. Mark. Res. 39, 331–348. doi:10.1177/147078539703900202.

Arcese, G., Lucchetti, M.C., Massa, I., Valente, C., 2018. State of the art in S-LCA: integrating literature review and automatic text analysis. Int. J. Life Cycle Assess. 23, 394–405. doi:10.1007/s11367-016-1082-0.

Arvidsson, R., 2019. On the use of ordinal scoring scales in social life cycle assessment. Int. J. Life Cycle Assess. 24, 604–606. doi:10.1007/s11367-018-1557-2.

Basso, B., Fiorentino, C., Cammarano, D., Schulthess, U., 2016. Variable rate nitrogen fertilizer response in wheat using remote sensing. Precis. Agric. 17, 168–182. doi:10.1007/s11119-015-9414-9.

Benoit-Norris, C., 2013. The Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA). Pre-Publication Version doi:10.1007/978-1-4419-8825-6.

Bittman, S., Brook, J., Bleeker, A., Bruulsema, T., 2013. Air quality, health effects and management of ammonia emissions from fertilizers. Air Qual. Manag. Can. Perspect. Glob. (261–277) doi:10.1007/978-94-007-7557-2_12.

Boulay, A.M., Bare, J., Benini, L., Berger, M., Lathuillière, M.J., Manzardo, A., Margni, M., Motoshita, M., Núñez, M., Pastor, A.V., Ridoutt, B., Oki, T., Worbe, S., Pfister, S., 2018. The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). Int. J. Life Cycle Assess. 23, 368–378. doi:10.1007/s11367-017-1333-8.

Brundtland, G.H., 1987. The Brundtland report: 'Our common future.'. Med. War 4, 17–25. doi:10.1080/07488008808408783, (accessed 10 January 2022).

Bruno, I., Lobo, G., Covino, B.V., Donarelli, A., Marchetti, V., Panni, A.S., Molinari, F., 2020. Technology readiness revisited: a proposal for extending the scope of impact assessment of European public services. In: Proceedings of the PervasiveHealth: Pervasive Computing Technologies for Healthcare, pp. 369–380. doi:10.1145/3428502.3428552.

Burchi, B., Zamagni, A., Buttol, P., Amerighi, O., 2013. Social Life Cycle Assessment of a new technology: analysis of potential social performance. SETAC Eur. 19th LCA Case Study Symp. LCA Mark. Res. policy Harmon. beyond Stand..

Bureau of Labor Statistics, 2021. Occupational Outlook Handbook, Agricultural Workers. U.S. Department of Labor https://www.bls.gov/ooh/farming-fishing-and-forestry/agricultural-workers.htm.

Ceicdata, 2021. Belgium number of employees: by industry. https://www.ceicdata.com/en/belgium/number-of-employees-by-industry (accessed 16 September 2021)

Chen, W., Holden, N.M., 2017. Social life cycle assessment of average Irish dairy farm. Int. J. Life Cycle Assess. 22, 1459–1472. doi:10.1007/s11367-016-1250-2.

Cordell, D., 2010. The story of phosphorus sustainability implications of global phosphorus scarcity for food security.

Country economy, 2021. National minimum wage. https://countryeconomy.com/national-minimum-wage (accessed 17 January 2022)

D'Amato, G., Cecchi, L., D'Amato, M., Annesi-Maesano, I., 2014. Climate change and respiratory diseases. Eur. Respir. Rev. Off. J. Eur. Respir. Soc. 23, 161–169. doi:10.1183/09059180.00001714.

D-NOSES consortium (2019) Odour pollution - a growing societal concern. d-NOSES policy brief #1 https://dnoses.eu/wp-content/uploads/2019/03/Policy-Brief_-Digital-A4-Europe_EN.pdf (accessed in 23 July 2021)

Darnhofer, I., Fairweather, J., Moller, H., 2010. Assessing a farm's sustainability: insights from resilience thinking. Int. J. Agric. Sustain. 8, 186–198. doi:10.3763/ijas.2010.0480.

Donham, K.J., Wing, S., Osterberg, D., Flora, J.L., Hodne, C., Thu, K.M., Thorne, P.S., 2007. Community health and socioeconomic issues surrounding concentrated animal feeding operations. Environ. Health Perspect. 115, 317–320. doi:10.1289/ehp.8836.

Abbas Drebee, H., Azam Abdul-Razak, N., 2020. The Impact of Corruption on Agriculture Sector in Iraq: Econometrics Approach. IOP Conf. Ser. In: Earth Environ. Sci. , 553 doi:10.1088/1755-1315/553/1/012019.

EEA, 2018. Environmental indicator report 2018. Support to the Monitoring of the Seventh Environment Action Programme. European Environment Agency.

EEC, 1991. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources.

Ejeta, G., 2009. Revitalizing agricultural research for global food security. Food Secur. 1, 391–401. doi:10.1007/s12571-009-0045-8.

Eurostat, 2021. Database - health. https://ec.europa.eu/eurostat/web/health/data/database (accessed 24 September 2021)

European Commission (EC), 2021. Pig meat: statistics regarding live piglets as well as different categories and qualities of pork https://ec.europa.eu/commission/presscorner/detail/en/IP_21_4584 (accessed 02 April 2021).

FAO, 2018. More people, more food, worse water? A global review of water pollution from agriculture, FAO of the United Nations & IWMI. https://www.fao.org/3/ca0146en/ca0146en.pdf (accessed 24 July 2021)

FAO, 2021a. AQUASTAT. https://www.fao.org/aquastat/statistics/query/results.html. (accessed 24 October 2021)

FAO, 2016. The state of food and agriculture, 2016, The Eugenics review. https://www.fao.org/3/i6030e/i6030e.pdf (accessed 13 January 2022)

FAO, 2021b. The state of food security and nutrition in the world 2021. 10.4060/cb4474en (accessed 10 January 2022)

FAO, 2017. Water for sustainable food and agriculture water for sustainable food and agriculture, a report produced for the G20 Presidency of Germany.
Fellmann, T., Domínguez, I.P., Witzke, P., Weiss, F., Hristov, J., Barreiro-Hurle, J., Leip, A., Himics, M., 2021. Greenhouse gas mitigation technologies in agriculture: regional circumstances and interactions determine cost-effectiveness. J. Clean. Prod. 317. doi:10.1016/j.jclepro.2021.128406.
Franze, J., Ciroth, A., 2011. A comparison of cut roses from Ecuador and the Netherlands. Int. J. Life Cycle Assess. 16, 366–379. doi:10.1007/s11367-011-0266-x.
Gallardo, R.K., Sauer, J., 2018. Adoption of labor-saving technologies in agriculture. Annu. Rev. Resour. Econ. 10, 185–206. doi:10.1146/annurev-resource-100517-023018.
Haines, A., McMichael, A.J., Smith, K.R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B.G., Campbell-Lendrum, D., Dangour, A.D., Davies, M., Bruce, N., Tonne, C., Barrett, M., Wilkinson, P., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. Lancet 374, 2104–2114. doi:10.1016/S0140-6736(09)61759-1.
Hannouf, M., Assefa, G., 2018. Subcategory assessment method for social life cycle assessment: a case study of high-density polyethylene production in Alberta, Canada. Int. J. Life Cycle Assess. 23, 116–132. doi:10.1007/s11367-017-1303-1.
Hurst, P., Termine, P., Karl, M., 2005. Agricultural workers and their contribution to sustainable agriculture and rural development. https://www.ilo.org/wcmsp5/groups/public/—ed_dialogue/—actrav/documents/publication/wcms_113732.pdf (accessed in 20 August 2021)
ILO, 2021. Agriculture: a hazardous work. https://www.ilo.org/safework/areasofwork/hazardous-work/WCMS_110188/lang–en/index.htm. (accessed 16 September 2021)
ISO 14040, 2006. Environmental management – life cycle assessment – principles and framework
Keeler, B., Gourevitch, J., Polasky, S., Isbell, F., Tessum, C., Hill, J., Marshall, J., 2016. The social costs of nitrogen. Sci. Adv. 2. doi:10.1126/sciadv.1600219.
Kim, J., 2018. Innovative technology in the agricultural sectors: opportunities for green jobs or exacerbation of rural youth unemployment? In: Proceedings of the Future of Work in Agriculture Conference. Washington D.C., USA. March 2019.
Kono, J., Ostermeyer, Y., Wallbaum, H., 2018. Trade-off between the social and environmental performance of green concrete: the case of 6 countries. Sustainability 10. doi:10.3390/su10072309.
Kühnen, M., Hahn, R., 2017. Indicators in social life cycle assessment: a review of frameworks, theories, and empirical experience. J. Ind. Ecol. 21, 1547–1565. doi:10.1111/jiec.12663.
Kumar, M., 2020. Social, economic, and environmental impacts of renewable energy resources. 10.5772/intechopen.89494
Lee, S.J., 2010. The occupational diseases of agricultural workers. Hanyang Med. Rev. 30, 305. doi:10.7599/hmr.2010.30.4.305.
Lenzen, M., Moran, D., Kanemoto, K., Geschke, A., 2013. Building eora: a global multi-region input-output database at high country and sector resolution. Econ. Syst. Res. 25, 20–49. doi:10.1080/09535314.2013.769938.
Levy, J., 2003. Health effects of atmospheric nitrogen emissions. Environ. Sci. Policy Sustain. Dev. 45, 14. doi:10.1080/00139150309604554.
Likert, R., 1932. A technique for the measurement of attitudes. Arch. Psychol. 22 (140), 55.
Maister, K., Di Noi, C., Ciroth, A., Srocka, M., 2020. PSILCA v.3.
Martin, M., Herlaar, S., 2021. Environmental and social performance of valorizing waste wool for sweater production. Sustain. Prod. Consum. 25, 425–438. doi:10.1016/j.spc.2020.11.023.
Mielcarek-bocheńska, P., Rzeźnik, W., 2021. Greenhouse gas emissions from agriculture in EU countries—state and perspectives. Atmosphere (Basel) 12, 1–18. doi:10.3390/atmos12111396.
Navi, M., Hansen, A., Nitschke, M., Hanson-Easey, S., Pisaniello, D., 2017. Developing Health-Related Indicators of Climate Change: Australian Stakeholder Perspectives. Int. J. Environ. Res. Public Heal.. https://doi.org/10.3390/ijerph14050552.
Nedelciu, C.E., Ragnarsdóttir, K.V., Stjernquist, I., Schellens, M.K., 2020. Opening access to the black box: the need for reporting on the global phosphorus supply chain. Ambio 49, 881–891. doi:10.1007/s13280-019-01240-8.
Numbeo. 2019. Pollution index by country 2019. https://www.numbeo.com/pollution/rankings_by_country.jsp?title=2019 (accessed 05 October 2021)
OEC, 2021. Observatory of economic complexity. Mixed mineral or chemical fertilizers. https://oec.world/en/profile/hs92/mixed-mineral-or-chemical-fertilizers (accessed 24 September 2021)
Pelletier, N., 2018. Social sustainability assessment of Canadian egg production facilities: methods, analysis, and recommendations. Sustainability 10, 1–17. doi:10.3390/su10051601.
Peters, G., Murphy, K., Adamsen, A., Bruun, S., Svanström, M., ten Hoeve, M., 2014. Improving odour assessment in LCA—the odour footprint. Int. J. Life Cycle Assess. 19, 1891–1900. doi:10.1007/s11367-014-0782-6.
Prasad, S., Singh, A., Korres, N., Rathore, D., Sevda, S., Pant, D., 2020. Sustainable utilization of crop residues for energy generation: a Life Cycle Assessment (LCA) perspective. Bioresour. Technol. 303, 122964. doi:10.1016/j.biortech.2020.122964.
Ramirez, P.K.S., Petti, L., Brones, F., Ugaya, C.M.L., 2016. Subcategory assessment method for social life cycle assessment. Part 2: application in Natura's cocoa soap. Int. J. Life Cycle Assess. 21, 106–117. doi:10.1007/s11367-015-0964-x.
Ridder, M.De, Jong, S.De, Polchar, J., & Lingemann, S. (2012). Risks and opportunities in the global phosphate rock market: robust strategies in times of uncertainty. https://www.phosphorusplatform.eu/images/download/HCSS_17_12_12_Phosphate.pdf (accessed in 26 October 2021)
Rotz, S., Gravely, E., Mosby, I., Duncan, E., Finnis, E., Horgan, M., LeBlanc, J., Martin, R., Neufeld, H.T., Nixon, A., Pant, L., Shalla, V., Fraser, E., 2019. Automated pastures and the digital divide: how agricultural technologies are shaping labour and rural communities. J. Rural Stud. 68, 112–122. doi:10.1016/j.jrurstud.2019.01.023.
Rounsevell, M., Metzger, M.J., 2010. Developing qualitative scenario storylines for environmental change assessment. Wiley Interdiscip. Rev. Clim. Chang. 1, 606–619. doi:10.1002/wcc.63.
Sahoo, P.K., Kim, K., Powell, M.A., 2016. Managing groundwater nitrate contamination from livestock farms: implication for nitrate management guidelines. Curr. Pollut. Rep. 2, 178–187. doi:10.1007/s40726-016-0033-5.
Salary Explorer, 2021. Salary and cost of living comparison. http://www.salaryexplorer.com/(accessed 29 September 2021)
Saritas, O., Kuzminov, I., 2017. Global challenges and trends in agriculture: impacts on Russia and possible strategies for adaptation. Foresight 19, 218–250. doi:10.1108/FS-09-2016-0045.
Siebert, A., O'Keeffe, S., Bezama, A., Zeug, W., Thrän, D., 2018. How not to compare apples and oranges: generate context-specific performance reference points for a social life cycle assessment model. J. Clean. Prod. 198, 587–600. doi:10.1016/j.jclepro.2018.06.298.
Statista, 2021. Number of employees in agriculture, forestry and fishery in Germany from 1991 to 2020. https://www.statista.com/statistics/669298/employees-agriculture-forestry-fishery-germany/(accessed 16 September 2021)
Sutton, M.A., Howard, C.M., Erisman, J.W., Billen, G., Bleeker, A., Grennfelt, P., … Grizzetti, B., 2011. The European Nitrogen Assessment: Sources, Effects and Policy Perspectives. Cambridge University Press.
Switzer, Y., 2019. Dangerous fertilisers: Swiss traders and human rights violations in Morocco 1–8.
Thonemann, N., Schulte, A., Maga, D., 2020. How to conduct prospective life cycle assessment for emerging technologies? A systematic review and methodological guidance. Sustainability 12, 1–23. doi:10.3390/su12031192.
Umstätter, C., Stark, R., Schmid, D., Schick, M., 2016. Auswirkung des technischen fortschritts auf die arbeitszeit in der landwirtschaft. Agrar. Schweiz 7, 204–209.
UNEP, 2009. Guidelines for social life cycle assessment of products. Management 15, 104.
UNEP, 2020. Guidelines for Social Life Cycle Assessment of Products and Organizations 2020. United Nations Environment Programme (UNEP) Norris, C., Traverso, M., Neugebauer, S., Ekener, E., Schaubroeck, T., Garrido, S., Berger, M., Valdivia, S., Lehmann, A., Finkbeiner, M., Arcese, G., 2020. (eds.).
United Nations, 2022. SDG indicators - metadata repository. https://unstats.un.org/sdgs/metadata/(accessed 12 January 2022)
Urbancová, H., Depoo, L., 2018. Impact of employee development in agricultural companies on commitment, loyalty and performance. Acta Univ. Agric. Silvic. Mendelianae Brun. 66, 803–811. doi:10.11118/actaun201866030803.
van Haaster, B., Ciroth, A., Fontes, J., Wood, R., Ramirez, A., 2017. Development of a methodological framework for social life-cycle assessment of novel technologies. Int. J. Life Cycle Assess. 22, 423–440. doi:10.1007/s11367-016-1162-1.
Vatsanidou, A., Nanos, G.D., Fountas, S., Baras, J., Castrignano, A., Gemtos, T.A., 2017. Nitrogen replenishment using variable rate application technique in a small hand-harvested pear orchard. Spanish J. Agric. Res. 15. doi:10.5424/sjar/2017154-10986.
Ward, M.H., Jones, R.R., Brender, J.D., de Kok, T.M., Weyer, P.J., Nolan, B.T., Villanueva, C.M., van Breda, S.G., 2018. Drinking water nitrate and human health: an updated review. Int. J. Environ. Res. Public Health 15, 1–31. doi:10.3390/ijerph15071557.
Werker, J., Wulf, C., Zapp, P., Schreiber, A., Marx, J., 2019a. Social LCA for rare earth NdFeB permanent magnets. Sustain. Prod. Consum. 19, 257–269. doi:10.1016/j.spc.2019.07.006.
Werker, J., Wulf, C., Zapp, P., 2019b. Working conditions in hydrogen production: a social life cycle assessment. J. Ind. Ecol. 23. doi:10.1111/jiec.12840.
WHO, 2016. Global health observatory data repository. https://apps.who.int/gho/data/view.main.BODAMBIENTAIRDALYS (accessed 16 September 2021)
Wilkinson, P., Smith, K., Joffe, M., Haines, A., 2007. A global perspective on energy: health effects and injustices. Lancet 370, 965–978. doi:10.1016/S0140-6736(07)61252-5.
Wohlenberg, J., Schneider, R.C.S., Hoeltz, M., 2020. Sustainability indicators in the context of family farming: a systematic and bibliometric approach. Environ. Eng. Res. 27. doi:10.4491/eer.2020.545, 200545–0.
World Bank, 2019. Worldwide governance indicators. https://info.worldbank.org/governance/wgi/#home (accessed 04 September 2021)
Xia, Y., Zhang, M., Tsang, D.C.W., Geng, N., Lu, D., Zhu, L., Igalavithana, A.D., Dissanayake, P.D., Rinklebe, J., Yang, X., Ok, Y.S., 2020. Recent advances in control technologies for non-point source pollution with nitrogen and phosphorous from agricultural runoff: current practices and future prospects. Appl. Biol. Chem. 63. doi:10.1186/s13765-020-0493-6.