



Social Life Cycle Assessment in agri-food systems: Insights from the literature and two case studies using PSILCA

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ABSTRACT

Social Life Cycle Assessment (S-LCA) complements Environmental Life Cycle Assessment (ELCA) by offering a structured approach to evaluate social sustainability. However, its application in agri-food systems—particularly combined with S-LCA databases—remains limited, despite its critical role in sustainability. This study investigates methodological and practical challenges of applying S-LCA to agri-food systems through a literature review, cross-validated by evidence from an empirical analysis of Swiss apple and greenhouse tomato production with the PSILCA v3 database. This mixed-methods approach captures confirmed and previously unrecognized challenges that neither a literature review nor an isolated case study would reveal alone. Our analysis identified 27 challenges, categorized into boundary conditions, S-LCA phases, and integration with other sustainability methods. General challenges included data quality, availability, and uncertainty, while agriculture-specific issues highlighted limited representation of farmers and inconsistent treatment of farm animals across S-LCA approaches. These findings underscore systemic barriers to capturing social impacts in agricultural systems and facilitating sustainable production. This work demonstrates that S-LCA, when combined with databases, offers a comprehensive approach to assess social risks and opportunities across agri-food life cycles. However, methodological advancements are needed to strengthen S-LCA's complementary role to ELCA to improve the sustainability of agri-food systems.

1. Introduction

While the environmental impacts of agricultural production have been extensively studied, with Life Cycle Assessment (LCA) being one of the most commonly applied methods (Yang et al., 2024), the social dimension of sustainability of agri-food systems has received comparatively less systematic attention, despite the increasing need for such evaluations (Chopin et al., 2021). Social sustainability of these agri-food systems is however essential to reach all Sustainable Development Goals (SDGs), including the goals around labor conditions, gender equity, migration and food security (Mancini et al., 2023). Unlike environmental assessments, which benefit from well-established frameworks, approaches for evaluating social impacts remain less harmonized and less developed (Orou Sannou et al., 2023). Social Life Cycle Assessment (S-LCA) addresses this challenge by offering a structured “methodology to assess social impacts across the entire life cycle of products and

services” (UNEP Benoit-Norris et al., 2020; International Standard Organisation (ISO), 2024). By considering all life cycle steps and relevant stakeholders, S-LCA can capture potential social impacts along a product's value chain and avoid burden shifting (Benedetto, 2016). This life-cycle perspective represents a key advantage of S-LCA over methods that focus either on single life cycle steps (Grenz et al.; Isaac et al., 2024) or single social aspects (Global Living Wage Coalition, 2018). S-LCA is therefore a very promising methodology for holistic social sustainability evaluations of agri-food systems.

S-LCA has been applied in different contexts ranging from the construction sector (Josa et al., 2025) to innovative technologies (Ziegler-Rodriguez et al., 2026). However, while its application to the agri-food systems is increasing, it remains limited (Petti et al., 2018a; Huertas-Valdivia et al., 2020; Tragnone et al., 2022). Existing studies underline its potential, such as accounting for multifunctionality (when a system provides multiple outputs) (D'Eusanio et al., 2018), and

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enabling assessment at different scales (micro, meso or macro-level) (Huertas-Valdivia et al., 2020; Macombe et al., 2013; Di Cesare et al., 2016). However, they also highlight persistent methodological challenges. These include limited data availability, unclear system boundaries and cut-off definitions, difficulties in linking social impacts to functional units, and a lack of consistency in indicator selection (Tragnone et al., 2022). Despite these insights, a structured classification of challenges specific to agri-food systems is still lacking, limiting progress toward more systematic and comparable assessments.

Most S-LCA studies in agriculture rely on primary data and focus on foreground processes, while background processes along global value chains are often overlooked. S-LCA databases such as PSILCA (GreenDelta and PSILCA, 2020) and the Social Hotspot Database (Social Hotspot Database, 2022) offer opportunities to address this gap, but their use in general and for agri-food systems particularly remains scarce (Bonilla-Alicea et al., 2021). In fact, Tragnone, D'Eusano (Tragnone et al., 2022) found four out of 24 publications that were using databases as a data collection method. Since 2022, we found four additional studies using a database to represent the social risks and opportunities of different agri-food systems (Tragnone et al., 2023a, 2023b; Rivera-Huerta et al., 2024; Vinci et al., 2024). While this is a clear increase, it remains limited compared to the number of S-LCA studies published to date. Using these databases introduces additional challenges for S-LCA, such as limited geographical resolution, as data are often provided at the country or sector level and do not capture regional specificities (Huertas-Valdivia et al., 2020).

While existing studies include reviews summarizing challenges in applying S-LCA to agri-food systems (e.g. (Tragnone et al., 2022; Guglielmetti Mugion et al., 2025; Martínez-Blanco et al., 2014)) and empirical studies testing S-LCA databases in specific agri-food contexts (Tragnone et al., 2023a, 2023b; Rivera-Huerta et al., 2024; Andrade et al., 2022), these works typically focus either on theoretical gaps or isolated case studies. Similarly, in other sectors, case studies using S-LCA databases highlight practical challenges (e.g. (Díez-Hernández et al., 2026)). To the best of our knowledge, no prior study combines a literature review with empirical case-study application to categorize and holistically assess the challenges of using S-LCA databases in agri-food systems. Our study addresses this gap, by combining a structured review of challenges reported in the literature with an empirical application of S-LCA to two case studies using an S-LCA database (PSILCA). This offers a more holistic picture grounded in practice of where and why these challenges arise than either approach could provide alone.

Current research gaps are addressed in our study by i) providing a clearly structured overview of methodological and practical challenges that future research needs to tackle to make S-LCA better suited for the systematic social sustainability assessment of agri-food systems, and ii) examining challenges related to the use of databases for S-LCA of agri-food products. Using a mixed-methods approach (Molina-Azorín et al., 2014), combining a literature review to identify challenges of S-LCA in agriculture (qualitative method) with an empirical application of S-LCA to two Swiss case studies covering open-field apples and tomatoes in greenhouses, we aim to support the development of more robust social sustainability assessments for agricultural systems in industrialized countries. Such development is essential for informed decision-making and sustainable engineering practices, supporting the transition toward resource-efficient and socially equitable food systems.

2. Background on social LCA and its challenges

S-LCA aligns with the methodology of environmental LCA (ELCA) covering all steps of a product's or technology's life cycle and follows the same four stages, namely (1) the goal and scope definition, (2) the inventory analysis, (3) the impact assessment and (4) the interpretation, as described in the S-LCA guidelines of the United Nations Environmental Program (UNEP) (UNEP Benoit-Norris et al., 2020). A main difference between S-LCA and ELCA is that S-LCA evaluates social impacts for six

stakeholder categories that can be affected by the activities related to the product's life cycle, namely workers, consumers, local communities, society, children and other value chain actors. The social impacts are then evaluated per stakeholder category with so-called impact sub-categories themselves assessed with impact indicators. While we use the term "stakeholder" in line with the UNEP guidelines, the International Standard Organisation (ISO) (International Standard Organisation (ISO), 2024) refers to them as "interested party" (Traverso et al., 2025). For workers, an impact subcategory would be fair salaries, which can, for example, be evaluated with an indicator quantifying the number of employees earning wages below poverty line (UNEP Traverso et al., 2021). The Methodological Sheets for subcategories in S-LCA developed by the UNEP facilitate the choice and definition of these indicators (UNEP Traverso et al., 2021). Not all stakeholder categories are necessarily relevant for all products, and the choice of the social impact to consider per stakeholder category is not straightforward since aspects related to appropriateness for the evaluated product, data availability and applicability all need to be considered. The S-LCA guidelines mention focus groups as a way to identify relevant stakeholder groups and indicators, or to define the relative importance of each social impact (UNEP Benoit-Norris et al., 2020).

Social impact assessment can follow two approaches in S-LCA: 1) the reference scale approach and 2) the impact pathway approach. The reference scale approach focuses on the social performance or social risks of a product system (e.g., practices implemented to manage social impacts) and evaluates social performance or risks using reference scales. Indicators are compared against a reference scale and assigned low, medium or high social risk or performance (e.g., the number of emergency protocols on accidents and injuries that are put in place relate to the health and safety of workers). The impact pathway approach aims to predict consequences of the product system (e.g., lower future well-being related to poor nutrition because of unpaid wages) and relies on quantified cause-effect pathways for the impact evaluation. Currently, available indicators of the impact pathway approach are largely restricted to the workers category. Hence when aiming to consider all stakeholders affected, the reference scale approach is often preferred in S-LCA studies (UNEP Benoit-Norris et al., 2020). The International Standard Organisation (ISO) (International Standard Organisation (ISO), 2024) introduced a terminological shift compared to the UNEP Guidelines for S-LCA. It refers to the impact pathway approach as social life cycle impact assessment, thereby distinguishing it from the reference scale approach instead of treating both as parallel options. Of these, the impact pathway approach, the social life cycle impact assessment in ISO terms, is better aligned with LCA (International Standard Organisation (ISO), 2006a; International Standard Organisation (ISO), 2006b).

In the **goal and scope definition stage**, the purpose of the study is specified, and methodological choices are made, such as the type of S-LCA, the use or not of an activity variable, the stakeholders, impact indicators to be considered and the background database to use. Activity variables are used to allocate impacts of an entire system, e.g., a clothing factory, to specific processes, e.g., the production of a t-shirt.

When evaluating a system using the life-cycle approach, one differentiates between the foreground and background system. The foreground system includes the processes directly influenced by the subject of the study and primary data collection is prioritized in this context. The background system encompasses all the processes supporting the foreground. Databases are typically used to represent this background system since primary data collection is not possible from a resources' point of view for these processes. Two main databases cover the background processes in S-LCA: the Product Social Impact Life Cycle Assessment (PSILCA) database and the Social Hotspot database (SHDB). Both combine an Input-Output model with a social assessment using "worker hours" as an activity variable. The social risks and opportunities are quantified as worker hours with a certain risk level per sector and country/region (Harmens et al., 2021). PSILCA relies on the EORA

multi-regional input-output model which covers more countries and sectors than the SHDB but less indicators (Lenzen et al., 2013). For PSILCA, the reference year for the social assessment is 2017, while it is not specified in the SHDB for the social assessment part. According to the guidelines on S-LCA, social risk is measured with generic, sector/country level data, in opposition to social performance measured with company-specific data (UNEP Benoit-Norris et al., 2020). As a result, using a S-LCA database implies an evaluation of social risk. In PSILCA, each indicator is assigned a risk value on a 6-point scale (no risk, very low risk, low risk, medium risk, high risk, very high risk) based on the observed indicator values for the process evaluated. These values depend on the country and sector analyzed. Further, the risk or opportunity is calculated by aggregating the scaled social risk of all involved processes along the life cycle per indicator and scored by multiplying the monetary input of each flow by the activity variable and the impact factor to obtain medium risk hours. Medium risk hours quantify the risk in worker hours for a single indicator linked to the average risk of generating 1USD of output in that sector (Tragnone et al., 2023b). In general, using a database to represent the background implies choosing the flows best representing the analyzed product in the inventory analysis stage.

In the **inventory analysis stage**, data for the definition and quantification of the indicators are collected, as well as data to represent all processes linked to the analyzed product's life cycle.

The **impact assessment stage** implies that the indicators are quantified using the data collected to indicate the potential social impacts associated with the evaluated life cycle.

Finally, in the **interpretation stage** results are interpreted, also considering available literature, methodological choices reflected upon and conclusions and recommendations drawn. A social hotspot analysis can be carried out by ranking the medium risk hours per indicator.

Although guidelines for the application of S-LCA are available, several challenges arise when applying them. Based on Tragnone, D'Eusaneo (Tragnone et al., 2022), we organized the challenges around three main categories: boundary conditions, the integration of S-LCA with existing sustainability evaluation methods and challenges linked to the four S-LCA stages (Fig. 1). Boundary conditions of S-LCA encompass external factors beyond direct control of the method such as data limitations and spatially varying social norms and regulations. Furthermore, integrating S-LCA with ELCA or comprehensive sustainability assessments requires coherent and traceable methodological approaches, which need to be developed, especially for agricultural contexts. In terms of the S-LCA stages, challenges can arise in the definition of

inventories, impact assessment and interpretation.

3. Materials and methods

3.1. Mixed-methods approach

We used a mixed-methods approach to identify the key challenges in applying S-LCA to the agri-food system using a database to describe the background processes. First, we screened the literature to categorize challenges in the application of S-LCA to agri-food systems according to Fig. 1. Second, we conducted a quantitative analysis by applying S-LCA to two case studies: conventional apple production in Switzerland and conventional tomato production in Swiss greenhouses. Third, we combined the findings of the literature review and the quantitative analysis to identify the key challenges of applying S-LCA in agri-food systems.

3.2. Literature review

The literature review followed a two-steps procedure conducted in Web of Science in February and April 2024 with no time constraints. Web of Science was chosen because its indices are curated and it covers disciplines of relevance to S-LCA very well. While Web of Science has a strong coverage of social sustainability topics, we cannot exclude that a complementary search in another database such as Scopus could have added studies to this review. A first literature search (S1) identified the main methodological challenges arising when applying S-LCA to agriculture relying on studies reviewing available S-LCAs in the field. With a second literature search (S2) S-LCA was targeted explicitly at studies reflecting on challenges in applying S-LCA to the agri-food sector. The keyword “challenges” was looked for explicitly in this second search string. The challenges were organized around the categories presented in Fig. 1. The search strings included different combinations of keywords related to “social life cycle assessment”, “agriculture”, and “challenges”. Full details of this literature review including the complete search strings, and the inclusion and exclusion criteria are provided in the SI, S1. In addition, the PRISMA workflow in the results’ section summarizes the number of papers reviewed.

3.3. Case study analysis

For the S-LCA case studies, we followed the S-LCA guidelines so that the terminology used in this paper aligns with the guidelines rather than the one used in the ISO norms (International Standard Organisation

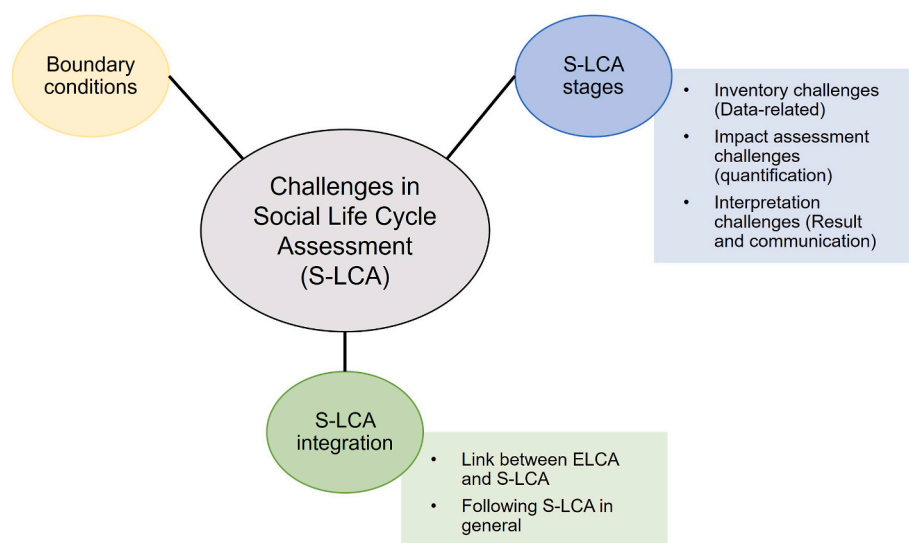


Fig. 1. – Categorization of Challenges in social life cycle assessment (S-LCA) in three main categories further specified in this study.

(ISO, 2024). The S-LCA guidelines described in Section 2.1 were applied to two case studies in Switzerland: conventional apple production and greenhouse production of conventional tomatoes. We selected these products because they are both produced and consumed a lot in Switzerland. Apples rank among the economically most relevant crop globally, are the second most important fruit in Europe and the third most important crop in Switzerland (Zachmann et al., 2024), representing 9.6% of total gross economic production value from all crops in Switzerland (Low et al., 2025) and about 60% of all fruit orchards in Switzerland in 2024 (Bundesamt für Landwirtschaft BLW, 2024a). Apples were the most consumed domestically produced fruit with a per capita consumption of 13 kg in 2022 (Bundesamt für Landwirtschaft BLW, 2024b) with self-sufficiency degree of about 95% (Bundesamt für Landwirtschaft BLW, 2024a). With 40'350 tons, tomatoes are one of the top three vegetables produced in Switzerland and, on average across all vegetables, the most consumed vegetable with a per capita consumption of 10.6 kg per year (Gemüse, 2024). The degree of self-sufficiency is about 44%, which implies that tomatoes are an important crop for domestic production in Switzerland (Gemüse, 2024). Although imports are also important for Swiss agriculture, this study focuses on domestic production, because we aim to evaluate the feasibility of using S-LCA databases to assess the social risks of Swiss products as illustrative applications in an industrialized country and hence identify additional challenges and opportunities of S-LCA applied to agri-food systems without handling between-country differences. Imported tomatoes are outside the system boundary of this case study.

3.3.1. Goal and scope definition

We set the system boundaries from the raw materials to the farm gate including the preparation of the sellable product. This decision aligns with current practices in ELCA, often stopping at farm gate. The functional unit was 1 kg of product (apple or tomato) and the reference flow in USD of product to match the flows available in the S-LCA database used. We followed the reference scale approach because it can cover more social impact categories and is the method mostly used so far in S-LCA, thus facilitating comparability with other published results. We further selected the PSILCA database starter version 3 rather than the SHDB because of its larger sectoral and geographical coverage and the clearer time-related coverage compared to the SHDB. We modelled our system with OpenLCA (GreenDelta and openLCA, 2025). Worker hours are the activity variable used in the PSILCA database. We then identified stakeholders per life cycle stage (Bouillass et al., 2021). We excluded consumers as the system boundaries stopped at the sellable product, thus excluding the buying and selling phases. All the other stakeholder categories of the S-LCA guidelines (workers, value chain actors, society, local community, and children) were considered for their inclusion in our study. A description of the stakeholders included per life cycle step is given in the SI, S3. This choice was made independently of the stakeholders available in PSILCA. The choice of the indicators and impact subcategories based on PSILCA refined the stakeholders that were ultimately considered in the study.

In the next step of the goal and scope definition stage, we selected the impact subcategories and indicators on which the presentation of the results should focus. First, we scanned the selected literature for social themes reported in more than one study following Tragnone, D'Eusano (Tragnone et al., 2022) for the stakeholder categories identified in the previous step. This yielded 19 social themes (SI, S4) that we further refined. *Value Chain Actors* were relevant at the raw material lifecycle step but not for the production and the preparation for sellable products as these steps were assumed to happen directly on the farm in Switzerland. Because of this and the focus of our study on domestic production, we excluded "supplier relationships" and "respect of intellectual property rights" from the social themes to be presented in the results. Second, we identified an indicator for each of the 17 social themes based on the indicators available in the PSILCA database (Maister et al., 2020). Because respective indicators were missing in

PSILCA, we did not cover the social themes of Public Commitment to Sustainability Issues, Prevention and Mitigation of Conflict, Technology Development and Corruption for *society*, and Fair Working Conditions and Work Satisfaction for *workers* in the S-LCA. The stakeholder category *children* was not included in the review by Tragnone, D'Eusano (Tragnone et al., 2022). Choosing an indicator for *children* was also more difficult because this category was not available in PSILCA. However, we included two indicators for the social theme "Contribution to economic development" of the *society* stakeholder in the presentation of the results, one directly reflecting the contribution of the sector to the economic development and the other listing the public expenditures on education. The latter could be a proxy for the *children* stakeholders as it is also listed under this stakeholder category in the Methodological Sheets (UNEP Traverso et al., 2021). Similarly, Tragnone, D'Eusano (Tragnone et al., 2022) did not provide an overview of social themes in agri-food S-LCA studies for the stakeholder category *local community*. Concerning the social themes available in PSILCA for *local community* we focused the presentation of the results on migration, respect of indigenous rights, and local employment. The indicators for access to material resources, environmental footprints, GHG footprints and safe and healthy living conditions were not dwelled further into when presenting the results to keep the focus on social issues. Several of these PSILCA indicators are operationalized through physical quantities already accounted for in environmental LCA — e.g., the indicator for access to material resources is measured as the total extraction of fossil fuels, biomass, ores and minerals per capita at country level (Maister et al., 2020). Presenting these indicators would risk double-counting the same underlying physical flow rather than adding a distinct social dimension. Still, we acknowledge that a shared physical metric is no guarantee that the social dimension of an indicator is fully captured by its environmental counterpart. For instance, an indicator that only measures total extraction volumes does not, in principle, capture the distributive question of who within a community has access to a resource. Depending on how such social indicators are precisely defined and operationalized, excluding them may therefore result in some loss of socially relevant information. The indicators on safe and healthy living conditions were also not presented as there is an ongoing debate on whether human health impacts should be attributed to ELCA, S-LCA, or in both (Bouillass et al., 2021). Moreover, we retained only indicators where the risk of double-accounting could be avoided. All indicators available in PSILCA were calculated, but the interpretation focused only on the selected indicators presented in this paper.

3.3.2. Inventory analysis

The data available in the chosen background database influences the steps taken in the inventory analysis. We developed two strategies based on whether a similar process existed in PSILCA or not. To model the social risks and opportunities of apple production, the PSILCA inventory "Apple and pear growing, NZ" was used as a starting point. To ensure a consistent input flow for the ecological life cycle assessment data and the social life cycle assessment data, we aligned the inventories of the Swiss Agricultural Life Cycle Assessment (SALCA) of "apples (orchard), conventional, plain region" and the corresponding PSILCA inventory (Nemecek et al., 2024). For the conventional tomato production, no corresponding PSILCA inventory was found. In this case, we modelled a new PSILCA inventory based on the ecoinvent inventory "Tomato, fresh grade (NL) tomato production, fresh grade, in heated greenhouse". Ecoinvent is a database often used in the environmental LCA of products (Ecoinvent Centre). We refer to the SALCA and ecoinvent reference inventories as "LCA reference inventory". The definition of the S-LCA inventory then followed four steps: (1) identify the necessary processes, (2) adapt the monetary flows, (3) define the risk values, and (4) set the activity variable.

The first step of **identifying the necessary processes** implied finding an adequate flow for all inputs and outputs of each product in PSILCA. For both products, Swiss inputs and outputs flows were missing

from the PSILCA database, so that Denmark was chosen as a proxy for Switzerland since it was assumed to be the closest match among European countries on which PSILCA had agricultural input, which are Spain, the United Kingdom and Denmark. The Gross Domestic Product (GDP) per capita of both countries is also the closest (CH = 151, DK = 128, UK = 98, ES = 92 GDP per capita in Purchasing Power Standards) (EUROSTAT and GDP per capita in, 2025). We did not define new processes whenever none was available for Switzerland since it would have implied a modelling effort far beyond the scope of this work.¹ Instead, a sensitivity analysis was carried out to evaluate the influence of the country of origin for these processes. Details on the choices of all flows are provided in the SI, S2 and the inventories for both products are given in the SI, S5.

In a second step, **the monetary flows were adapted**. The amount corresponding to each input flow, was obtained by multiplying the quantities available in the reference LCA inventories for each remaining process in the Swiss apple and tomato S-LCA inventory by a given price. Prices were taken from farm accountancy handbooks (cost catalogues) and publicly available price lists of different organizations. Detailed references are provided in the SI, S2.

In a third step, we set the **risk level values** for all indicators per product. We ensured that the risk level values of all indicators corresponded to the risk values of the PSILCA process “products of agriculture, forestry and fishing, CH”. This process was used as reference, as it was the process representing best the Swiss agricultural sector and potential risks associated with it. For some indicators, this PSILCA process reported “no data”, so that further investigation was necessary (SI, S2). The risk levels were the same for apple and tomato production.

In a fourth step, the **activity variable**, meaning the value assigned to each indicator, was set based on Equation (1). The value for the quotient was taken from the process “products of agriculture, forestry and fishing, CH” (=0.00936h) and the price of the product matched the price mentioned in the second step of adapting the monetary flow.

$$\text{Activity variable} = \frac{\text{Unit labour costs}}{\text{Mean hourly wage}} \times \text{price of product} \quad (1)$$

We defined different scenarios to evaluate the sensitivity of our results to some of the assumptions:

- S_pesticides: the input flow describing pesticides manufacturing in Denmark was replaced by a flow describing pesticides manufacturing in Venezuela. We selected Venezuela to assess how sensitive results are to the country of origin of the pesticides, as we expect differences in production standards between both countries.
- S_input: the costs linked to the input flow with highest costs after “Agricultural services; landscape gardeners etc., – DK” were doubled (S_input_plus) and halved (S_input_minus).
- S_manualwork: the input flow describing manual work “Agricultural services; landscape gardeners etc., – DK” was replaced by “Agricultural services; landscape gardeners etc., UK”
- S_workingcost: The labor costs were doubled (S_workingcost_doubled) and halved (S_workingcost_halved).

3.3.3. Impact assessment

For the impact assessment, we used the Social Impacts Weighting Method available in PSILCA to calculate the risk hours linked to each indicator. The costs of each input flow were multiplied with the activity variable and the characterization factor of each impact subcategory. We used a cut-off of 1E-9 as the loss of details in calculation was deemed acceptable (Maister et al., 2020).

¹ The Danish process, for example, includes processes related to the manufacturing of pharmaceuticals, or dyes for which no equivalent is available in Switzerland so that assumptions would have been needed to define these processes for Switzerland too.

3.3.4. Interpretation

For the interpretation, we chose to focus on a hotspot analysis per product and a comparison of the medium risk hours of each subcategory indicator for the different scenarios of the sensitivity analysis.

4. Results and discussion

The results of the literature review consist of the main findings of existing literature related to the challenges presented in Fig. 1. Furthermore, we present hotspot and sensitivity analysis of the two case studies on apple and tomato production in Switzerland. Based on both, a table summarizing the key challenges of applying S-LCA in agri-food systems in industrialized countries is presented combining the findings from the literature review and the case studies.

4.1. Results of the literature review

Overall, 17 papers from 73 were kept that cover challenges faced in the application of S-LCA and 11 from 82 to see how these challenges were handled in the agricultural context (SI, S1). Information on challenges and opportunities of S-LCA in the agricultural context could only be obtained from 10 papers as displayed in the PRISMA flow chart (Fig. 2). Despite the use of Web of Science as a unique bibliographic database, this small number of studies likely reflects the limited amount of research in this area to date. Using also the Scopus database would have been unlikely to yield a significant number of additional literature items of relevance. Complementing this literature review by a case-study in mixed-methods research seems therefore to be a reasonable approach to improve the coverage of challenges faced when applying S-LCA to agri-food systems. The results of the literature review are presented and discussed in sections 3.3 and 3.4 together with the challenges identified through the case studies.

4.2. Case study results

4.2.1. Hotspot analysis

Table 1 lists the results of the chosen subcategory indicators of the S-LCA for 1 USD of produced apples. The color scheme goes from green to red according to the increasing values of the indicator: Green-marked low-risk values indicate a low likelihood of social risks, based on the activity variable described in Section 2.4.1. In contrast, high-risk values marked in red indicate a substantial social risk within the analyzed food value chain, in our case for apples or tomatoes. Only the impact categories chosen in the methods section are displayed. It is important to mention that higher values are related to higher risks for all indicators except “contribution of the sector to economic development” and “public expenditures on education”, where higher values should be interpreted positively. They represent higher contributions to the gross domestic product.

The high values of the category “fair salary” imply a high risk driven by the social risk indicators of this category for workers in Switzerland (66%) and for the agricultural services process from Denmark (26%), as shown in the contribution analysis in SI, S6. The agricultural services encompass the manual work on the field such as mulching, application of plant protection products, fertilizer applications etc. This category highlights a potential risk for the *workers* due to their low salary compared to the costs of living in Switzerland (Maister et al., 2020). The result is directly linked to Swiss conditions, as the main driver is the actual apple growing process. Another risk for the *workers*’ representation is related to trade unionism due to the low trade union density observed in Switzerland which results in a high risk for this indicator. Again, the actual apple growing process is the main driver (98%, SI, S6). The risk potential for discrimination, racism or social conflicts ranks as relatively high for the *local community* stakeholder (category “international migrant stock”), given the high share of migrant workers in the labor force present in Switzerland. Finally, for the *value chain actors*, the

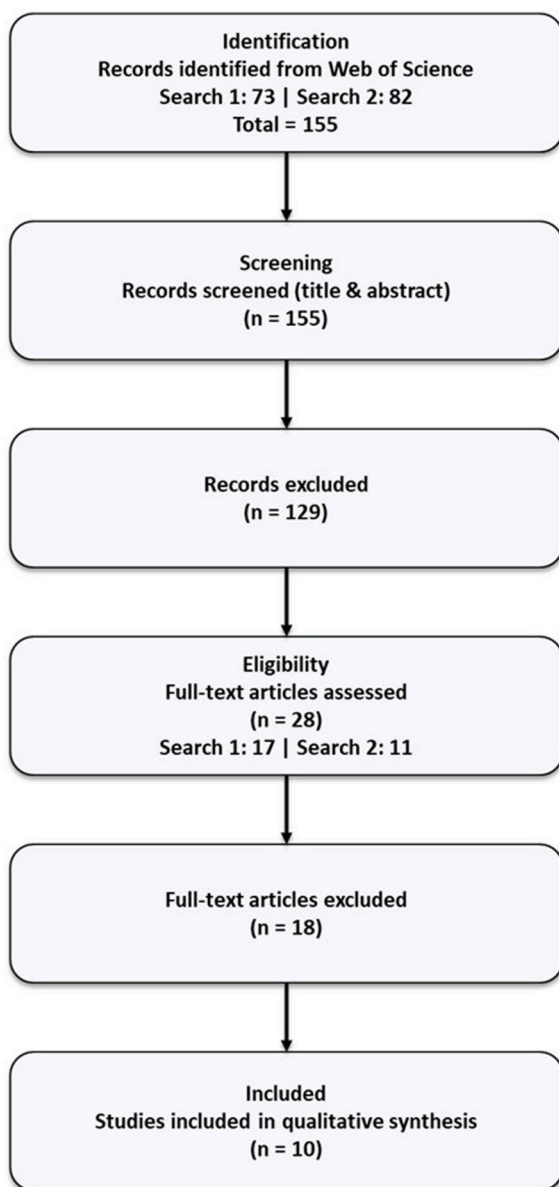


Fig. 2. – PRISMA flow chart displaying of the literature review.

lack of membership in an initiative promoting social responsibility along the life cycle of apple production (e.g., wholesale trade and commission trade, manufacture of construction materials of metals) leads to a high risk for the indicator promoting social responsibility. Since agricultural services from Denmark mainly drive this result (61%), the use of a Swiss-specific process might change the conclusion. All other indicators, including the ones for *society* and *children*, show rather low risk scores. It is essential to investigate the main drivers of the results to identify which country attributes are actually responsible for the results and whether country-specific conclusions can be drawn or not.

The results of the selected indicators for 1 USD tomatoes produced in a Swiss greenhouse are provided in Table 2. As for apples, higher values indicate higher risks for all impact categories except the ones belonging to the stakeholder *society* where higher values represent higher contributions to gross domestic product and are hence opportunities and not risks. It appears that the risk in tomato production in the “fair salary” category is the highest, as employees in low-wage sectors must cope with the high Danish and Swiss costs of living. The drivers of the outcomes in the “fair salary” category are the same for tomatoes and apples (SI, S6). The other three impact categories (trade unionism,

international migrant stock, and social responsibility) with the highest risk hours for tomato production are the same as for apple production. This makes sense as in Switzerland (i) only a low share of workers is unionized and (ii) the share of the migrants and thus the risk for discrimination is high, especially in low-paid sectors like agriculture. The situation in Denmark likely drives the result for the social responsibility indicator since agricultural services are an important driver (SI, S6). This suggests that in Denmark *value chain actors* show low participation in initiatives and foundations that promote social responsibility along the entire system. All other impact categories show relatively low levels of medium risk hours. As for apples, the social responsibility indicators are partly driven by the Danish proxy process, while fair salary, trade unionism and international migrant stock are directly linked to Swiss-specific conditions. To summarize, apples and tomato production in Switzerland show both the highest social risks in fair salary, international migrant stock and trade unionism. For all three indicators and both products, Swiss-specific conditions (high costs of living, high share of migrant workers, and low share of unionized workers) are driving these results.

4.2.2. Sensitivity analysis

For apples, changing the process describing manual work from Denmark (DK) to the United Kingdom (UK) (S_manualwork) changes the medium risk hours of the impact categories the most and so also the identification of the social risk hotspots (SI, S7). Especially, the frequency of forced labor, social security expenditures, women and men in the sectoral labor force, and expenditures on education indicator values change between 0.7- to 4- fold when using the process of agricultural services in the UK instead of the one of DK. The increase in the risk of forced labor is due to the different types of inputs associated with each supply flow. On the other hand, the increase in social security expenditures is directly linked to the higher risk level of this indicator in the UK compared to Denmark. Specifically, workers in the UK face a greater likelihood of not having social protection if they are unable to work, which contributes to increased social security costs. This contrast highlights how variations in social protections between countries impact the risk for workers. It is important to mention that both values remain low. The risks associated with men and women in the sectoral labor force, both already low, decrease further meaning that the risk in the UK of having men and women underrepresentation in specific sectors is lower than in Denmark. Finally, we need to note that considering manual work in the UK compared to DK improves the fair salary's indicator performance, displaying a better alignment of wages and living costs in the UK compared to DK.

Decreasing the monetary input necessary for pesticides manufacturing (S_input_minus) or manual work (S_workingcost halved) both lead to lower medium risk hours in all impact categories. The decrease is between 1 and 23% for pesticide manufacturing and around 27% for the manual work, except for trade unionism, weekly hours of work per employee and international migrant stock. For the latter three indicators, the percentages change is smaller, since for those indicators, the direct input flows to apple production in Switzerland were mainly driving the results. Greater monetary input necessary for pesticides manufacturing increases the medium risk hours of the indicators. Finally, changing the country of origin of the pesticides from Denmark to Venezuela (S_pesticides) barely influences the impact categories' results, highlighting the dominance of direct input flows to apple production as well as manual work. Over all scenarios, fair salary, trade unionism, promoting social responsibility and international migrant stock are always the top four indicators in terms of social risks, showing the relative robustness of this evaluation. The exact values are provided in the SI, S7.

For tomatoes too, using agricultural services from the UK instead of DK changes the impact category results the most. The results differ from those for apples for the social risks child labor and association and bargaining rights. The results for these categories increase more in the case of tomatoes than apples when changing manual work from DK to

Table 1

– Hotspot analysis for the social risks and opportunities of the production of 1 USD of apples.

Stakeholder	Impact category	Reference unit	Result
Workers	Association and bargaining rights	ACB med risk hours	0.05
Workers	Child Labour, total	CL med risk hours	0.03
Workers	Fair Salary	FS med risk hours	7.80
Workers	Fatal accidents	FA med risk hours	0.00
Workers	Frequency of forced labour	FL med risk hours	0.00
Workers	Men in the sectoral labour force	M med risk hours	0.00
Workers	Non-fatal accidents	NFA med risk hours	0.01
Workers	Social security expenditures	SS med risk hours	0.09
Workers	Trade unionism	TU med risk hours	4.42
Workers	Weekly hours of work per employee	WH med risk hours	0.45
Workers	Women in the sectoral labour force	W med risk hours	0.08
Society	Contribution of the sector to economic development	CE med risk hours	0.03
Society / Children	Expenditures on education	EE med risk hours	0.01
Local community	Indigenous rights	IR med risk hours	0.02
Local community	International migrant stock	IMS med risk hours	4.43
Local community	Unemployment	U med risk hours	0.01
Value Chain Actors	Anti-competitive behaviour or violation of anti-trust and monopoly legislation	AC med risk hours	0.04
Value Chain Actors	Promoting social responsibility	PSR med risk hours	0.39

Table 2

– Hotspot analysis for the social risks and opportunities of the production of 1 USD of greenhouse tomatoes.

Stakeholder	Impact category	Reference unit	Result
Workers	Association and bargaining rights	ACB med risk hours	0.04
Workers	Child Labour, total	CL med risk hours	0.03
Workers	Fair Salary	FS med risk hours	10.16
Workers	Fatal accidents	FA med risk hours	0.00
Workers	Frequency of forced labour	FL med risk hours	0.00
Workers	Men in the sectoral labour force	M med risk hours	0.00
Workers	Non-fatal accidents	NFA med risk hours	0.04
Workers	Social security expenditures	SS med risk hours	0.09
Workers	Trade unionism	TU med risk hours	6.13
Workers	Weekly hours of work per employee	WH med risk hours	0.62
Workers	Women in the sectoral labour force	W med risk hours	0.11
Society	Contribution of the sector to economic development	CE med risk hours	0.03
Society / Children	Expenditures on education	EE med risk hours	0.01
Local community	Indigenous rights	IR med risk hours	0.02
Local community	International migrant stock	IMS med risk hours	6.18
Local community	Unemployment	U med risk hours	0.01
Value Chain Actors	Anti-competitive behaviour or violation of anti-trust and monopoly legislation	AC med risk hours	0.04
Value Chain Actors	Promoting social responsibility	PSR med risk hours	0.34

the UK since both flows rely on different inputs.

Halving or doubling the input costs related to the construction of the greenhouse (S_{input_minus} and S_{input_plus}) changes the social risk for

non-fatal accidents because of the strong influence of the greenhouse's construction: increasing its input increases the risk of non-fatal accidents during its construction. Changing the country of origin for pesticide

manufacturing (S_{pesticides}) barely influences the results because this input flow is very marginal compared to the other flows linked to manual work or the greenhouse's construction.

Overall, the results of the sensitivity analysis are comparable between Swiss conventional apple and tomato production. All scenarios identified the same five impact categories with highest risks. This supports the use of S-LCA to identify hotspots along the value chain of products, also in the case of agri-food products where processes for the country of interest might be missing. Further, we showed that the choice of the proxy country and the quantification of the monetary input of the input flow with highest amount influenced the impact category values the most. Identifying important flows in S-LCA based on life cycle costing as suggested by Pérez-López, Rajaonison (Pérez-López et al., 2025) might therefore be helpful to streamline data collection efforts. Finally, we highlighted that some production-specific flows such as the greenhouse construction influence only some impact categories.

Comparing our results with previously published literature, as it is typically done in environmental LCA, is more difficult for S-LCA, primarily because of the lack of available studies and the limited use of background databases. In fact, we did not find any S-LCA study on apple production, let alone studies with a specific focus on Switzerland. The only S-LCA study on tomato production evaluated the social sustainability of tomato production in Italy following the S-LCA guidelines, without using any database and relying mostly on primary data from companies along the life cycle of tomato production (Petti et al., 2018b). However, we observe that similar stakeholder groups and similar indicators are typically used to display social risks in European agricultural systems. Petti et al. (2016) also report social risks for workers and local community. More specifically, the indicators of freedom of association and collective bargaining, child labor, fair salary, working hours, forced labor, and equal opportunity for workers and indigenous rights for the local community are common to this study (Petti et al., 2018b).

Drawing actionable recommendations from the case studies was not the primary aim of this research and is particularly difficult given the lack of data on country-specific processes. Instead, we identified several points that need to be addressed before S-LCA can be routinely used for decision-making. A better understanding of the costs of each input would help prioritize which ones to define most accurately, since we showed with the sensitivity analysis that the flows with highest input also drove the results the most. Relatedly, the exclusion of some PSILCA indicators to avoid double-counting with ELCA may have resulted in some loss of socially relevant information. Clarifying how such indicators can be measured in a way that is both non-redundant with ELCA and representative of their social content would be a useful methodological development of S-LCA. Having more S-LCA results for agricultural products would increase the understanding of such studies among stakeholders. Finally, it could be recommended to develop a stakeholder category for *farmers* jointly with different sustainability experts to account for all specificities of this stakeholder group. Related to this new stakeholder category comes the need for new, specific indicators.

4.3. Methodological and practical challenges

The literature review and the experience gained from the case study highlighted a series of generic challenges organized into challenges related to the S-LCA stages, boundary conditions, and S-LCA integration, which apply to S-LCA of agri-food systems. These generic challenges include, amongst others, the resource intensity and difficulty of data collection as well as issues around data quality in the inventory phase of S-LCA, and the lack of guidance on the choice of indicators and stakeholder categories in the impact assessment phase of S-LCA, which hinders the comparability of S-LCA and the difficulty of comparing results of ELCA and S-LCA studies (Huertas-Valdivia et al., 2020; Tragnone et al., 2022; Martínez-Blanco et al., 2014; Ayassamy et al., 2023; Pollok et al., 2021; Kühnen et al., 2018). Fewer studies reported generic challenges associated with the interpretation phase. Pollok, Spierling

(Pollok et al., 2021) criticized the fact that S-LCA often connects social impacts to corporate behavior rather than to processes and the missing link between S-LCA impact subcategories and Sustainability Development Goals (SDGs). Kühnen and Hahn (Kühnen et al., 2018) and Arcese, Lucchetti (Arcese et al., 2016) challenge how and under which conditions S-LCA results can be used in companies.

Only Kühnen and Hahn (Kühnen et al., 2018) mentioned challenges about the boundary conditions around S-LCA that might hamper its application. These were a lack of management commitment, resource constraints and limited market incentives. They argued that ensuring management commitment, planning enough resources and putting market incentives were necessary to increase the motivation for conducting S-LCAs, easing data collection and ensuring the subsequent use of the S-LCA results. These generic challenges could also apply in the context of agri-food systems.

Finally, challenges around S-LCA integration relate to the challenges identified so far: Pollok, Spierling (Pollok et al., 2021) and Arcese, Lucchetti (Arcese et al., 2016) both asked for more comparability and transparency in S-LCA studies. Pollok, Spierling (Pollok et al., 2021) further demanded a more critical reflection as to whether S-LCA is the correct method for a given case study. This aspect is particularly relevant in the context of agri-food systems since social evaluations at the farm level with country- and farm-specific indicators are often preferred over more generic S-LCAs. Kühnen and Hahn (Kühnen et al., 2018) also mentioned a lack of technical know-how of social assessment methods by the practitioner's using S-LCA, while Tragnone, D'Eusonio (Tragnone et al., 2022) regretted that the use phase is often not assessed in S-LCA. Finally, Huertas-Valdivia, Ferrari (Huertas-Valdivia et al., 2020) and Tallentire, Edwards (Tallentire et al., 2019) highlighted the poor representation of animals in S-LCA. Combining S-LCA with other sustainability assessment methods was found challenging because of difficulties of linking results to the functional unit of the assessment as well as of defining the system boundaries of the assessment (Tragnone et al., 2022; Martínez-Blanco et al., 2014; Pollok et al., 2021; Arcese et al., 2016). The challenge related to interpreting outcomes of sustainability evaluations across all three dimensions was also cited (Huertas-Valdivia et al., 2020; Martínez-Blanco et al., 2014; Arcese et al., 2016), potentially related to the fact that the interpretation phase is often insufficiently considered in S-LCA (Tragnone et al., 2022; Pollok et al., 2021).

Challenges more specific for agri-food systems were also identified. First, the indicators available in the PSILCA database used to represent the background were not always easily relatable to agri-food value chain processes and including custom-made indicators to this database would have required extensive data collection and modelling effort. Second, the use of worker hours as activity variable, implied in the basic versions of PSILCA, can be difficult to grasp for indicators not related to workers. Third, we were confronted with a lack of agricultural-specific flows in the database used, especially in the context of industrialized countries. Fertilizers were, for example, only available from the United Kingdom and Denmark and pesticides only from Spain, Denmark and the United Kingdom. Finally, the lack of specificity for agri-food systems was also present in relation to available stakeholders. This was particularly the case since we used a database to represent the background but it is also encountered in S-LCA applied to agri-food systems in general. Similar challenges were observed when applying database-supported S-LCA to innovative technologies (Díez-Hernández et al., 2026). Farmers represent a particular category with specificities found in workers as well as in value chain actors and would require deriving indicators accounting for these specificities. The same applies to animals, which, despite various initiatives, are still not routinely included in S-LCA studies. So far, animals are either included as a specific stakeholder category (Tallentire et al., 2019; Zira et al., 2020), considered through specific indicators within existing stakeholder groups in S-LCA (Møller et al., 2024; Mann et al., 2025), or through animal welfare indicators within LCA (Turner et al., 2023). Recent advances in the development of indicators for other stakeholder categories, such as children

(Aguilar-Planet et al., 2026), could be promising ways to better account for animals and farmers in agri-food S-LCA. Animals were not assessed in the case studies of this paper, as PSILCA does not include animal welfare in its default indicator set.

The mixed-methods research allowed us to identify challenges that have not been explicitly discussed in previous studies, most notably the lack of country-specific inventory flows. In the case of Swiss production, key information on upstream and production processes was missing at the required geographical resolution, limiting the ability of S-LCA to capture national specificities. This highlights the need to specify country-specific inventory flows and to systematically collect data to close existing gaps.

Our results confirm that several limitations reported in earlier studies remain. Two recent assessments of social risks in European agri-food products (honey and sugared almonds) highlighted structural constraints related to the use of PSILCA (Tragnone et al., 2023a, 2023b). In particular, the country- and sector-level resolution of PSILCA and the lack of agri-food-specific indicators reduce result representativeness, a limitation that is reinforced by our Swiss case study. Moreover, Tragnone, Serreli (Tragnone et al., 2023b) suggested that S-LCA results may be influenced by the monetary input values used in PSILCA; our sensitivity analysis provides empirical evidence of this effect and helps identify priorities for future S-LCA database development. Notably, neither study explicitly mentioned the lack of country-specific inventory flows, which proved critical in the Swiss context.

4.4. Avenues for future research

The use of databases in S-LCA in the context of agri-food systems could be facilitated with more guidance on their use and on interpreting their results. Despite consulting several tutorials (GreenDelta. Webinar, 2016), we struggled to easily understand how a S-LCA should be conducted and interpreted using a S-LCA database. Step by step guides including suggestions on the interpretation could help solve challenges related to the use of databases in S-LCA and the frequent neglect of the interpretation phase. Such guides are not only necessary for the use of S-LCA databases but also for the choice of stakeholders and impact categories. The work of Bouillass, Blanc (Bouillass et al., 2021) is very important in this respect. Including these recommendations in official documents such as the S-LCA guidelines could be helpful.

The interpretation of the impact category results generated using a background database could also benefit from a direct quantification of the indicators instead of using the activity variable of worker hours. For example, interpreting hours of child labor risk is slightly less straightforward than interpreting the percentage of child labor associated with different inventory flows. This is possible in the professional and developers' versions of the PSILCA database (Springer et al., 2024).

Further, to facilitate comparability and integration of environmental and social LCA, a harmonization of the terms used to describe the flows in background databases of both would be useful.

5. Conclusions

This study highlights key challenges in the application of S-LCA to agri-food systems based on findings from a mixed-methods approach combining a literature review and a case-study on greenhouse tomato and apple production in Switzerland using OpenLCA v2.4 and PSILCA database starter version 3. We identified 27 challenges associated with S-LCA application to agri-food products categorized into three main categories: boundary conditions, the S-LCA phases and the integration of S-LCA with other sustainability evaluation methods. These challenges include both generic issues, such as those related to data collection, quality, uncertainty and appropriateness in the inventory stage of S-LCA and agriculture-specific ones, such as lacking consideration of specificities associated with farmers.

We demonstrate that S-LCA combined with available databases is

currently the only method capable of assessing the full life cycle of agricultural products, including background processes, thus capturing a comprehensive view of social risks and opportunities. Despite the identified challenges, our findings underscore the novelty of S-LCA as a tool for identifying social hotspots and potential burden shifts that might be overlooked by other assessment methods. We also show its robustness in identifying these hotspots independently of methodological choices. Addressing the identified challenges through improved guidance on indicator selection, agriculture-specific stakeholder inclusion, database integration, and the consideration of country-specific flows, especially when products from different countries are compared will enhance the applicability of S-LCA in agricultural sustainability evaluations, ultimately supporting better-informed decision-making and more sustainable agricultural practices.

CRedit authorship contribution statement

Mélanie Douziech: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Nadja El Benni:** Writing – review & editing, Methodology, Conceptualization. **Stefan Mann:** Writing – review & editing. **Melf-Hinrich Ehlers:** Writing – review & editing. **Andreas Roesch:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cesys.2026.100522>.

Data availability

No data was used for the research described in the article.

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