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Exploring the role of social life cycle assessment in transition to circular economy: A systematic review

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ABSTRACT

Transitioning to a circular economy (CE) may create unintended social consequences. This systematic review analysed 45 published studies from 2009 to 2023 that evaluate these consequences using social lifecycle assessment (S-LCA), a tool based on the UNEP Guidelines. Most studies focused on circular activities like energy recovery and material recycling rather than reuse, remanufacturing, and repair. Worker-related issues like health, safety or fair wages were more frequently reported than impacts on consumers or society. Challenges in S-LCA application for CE include defining system boundary, identifying affected stakeholders, selecting relevant impact categories and indicators, obtaining verifiable data inventory, and addressing subjectivity in impact interpretation. A solution identified through the review was to enhance stakeholder involvement across industries to identify emerging social risks during the transition to CE. Periodically revising the UNEP Guideline based on these risks will provide a uniform framework for continued use of S-LCA in evaluating the transition to CE.

1. Introduction

1.1. Transition towards a circular economy

It is estimated that the global economy is only 7.2 % circular, i.e., over 90 % of the material input is not recovered (Circle Economy, 2023). Nevertheless, businesses may drive the adoption of a circular economy (CE) by implementing improved resource recovery initiatives, enhancing supply chain management, and advocating for end-of-life responsibility to minimize waste disposal (Barros et al., 2021).

The transition to CE can take various pathways outlined in the 9R-framework such as R0 refuse, R1 rethink, R2 reduce, R3 reuse, R4 repair, R5 refurbish, R6 remanufacture, R7 repurpose, R8 recycle, and R9 recover (Potting et al., 2017). These pathways or activities are prioritized in order of technical innovations, energy or resources used (Potting et al., 2017). In the design phase, embracing circularity involves refusing conventional production methods, rethinking supply chains, and reducing material requirements. As the process advances to the consumption phase, in a CE users are encouraged to adopt practices such as reusing (including resale), repairing, refurbishing, remanufacturing, and repurposing products, with and without technical assistance. When a product reaches the end of its life, there is a potential for recycling materials (partly or completely) to substitute virgin resources or recovering energy.

1.2. Social consequences of transitioning to CE

Kirchherr et al. (2023) suggest that CE should "aim to promote value maintenance and sustainable development, creating environmental quality, economic development, and social equity, to the benefit of current and future generations." However, despite aiming for overall sustainability, the social impact of transitioning to CE on workers, consumers, communities, and citizens may remain hidden (Schroeder et al., 2019). Suckling and Lee (2017) demonstrated this by comparing two common circular practices deployed for mobile phones (1) recycling at the end of first life (EoFL) and (2) reuse at EoFL followed by recycle. Recycling at EoFL enables the recovery of valuable metals, eases the burden on society and the environment resulting from the extraction of virgin ore, and ensures that these metals will not end up in a landfill. In contrast, reuse at EoFL followed by recycling offers a social benefit by providing access to the technology to a second user and prolonging product life. However, option one offers a shorter total lifespan of the

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phone since it is used only once, and an added environmental burden is related to making components to replace the discarded product. Whereas option two is only advantageous if the mobile phone is exported to a country with adequate waste management systems, to prevent health risks for the local communities at the end-of-second life (Umair et al., 2015). For instance, Shaikh et al. (2020) reported that in Pakistan importing electronic waste or e-waste for recycling has created many new jobs. But the recycling is mainly done by informal recyclers, and the net economic cost of US$ 203–5101 per worker exceeded the economic benefits derived from recycling by 2.6–4.7 times. The costs were related to reduced productive capacity, medical expenses, low wages from recycling and opportunity cost arising from low levels of literacy and value of life (Shaikh et al., 2020).

Social sustainability has been evaluated using Sustainability Reporting Standards by Global Reporting Initiative (GRI), the International Guidance Standards on Social Responsibility (ISO 26000), SA8000 by Social Accountability International, and AA1000 by the Institute of Social and Ethical Accountability (Messmann et al., 2020). Living wage, jobs created, and working hours are single indicators used for measuring the social impacts (Solarte-Toro et al., 2023). Human Development Index, Social Progress Index, or Gross National Happiness are used as indicators for national and regional level social sustainability (Stabler, 2023). Social Life Cycle Assessment (S-LCA) has also emerged as a tool for identifying social hotspots across a product's life cycle (Benoît et al., 2010). A social hotspot is any production activity in a unit process that may be a risk for the stakeholders who are the people that are influenced or may influence the investigated product systems (UNEP, 2020).

1.3. Measuring social sustainability of CE using S-LCA

S-LCA is a methodological framework to assess positive and negative social impacts throughout a product's lifecycle including stages of raw material extraction, manufacturing, distribution, use, maintenance, recycling, and disposal (Andrews et al., 2009). The first systematic guideline for performing an S-LCA was published in 2009 by the United Nations Environment Program or UNEP with Society of Environmental Toxicology and Chemistry or SETAC (Andrews et al., 2009). The guideline was revised in 2020 based on S-LCA practitioners' inputs (UNEP, 2020). Hereafter the revised version will be referred to as 'the UNEP Guideline.' S-LCA is based on the framework reported in ISO 14040 and 14044 standards for the environmental LCA and comprises four stages: goal and scope definition, inventory (data collection), impact assessment, and interpretation (ISO, 1997; 2006). In the UNEP Guideline, people involved in a product's life cycle are classified into six stakeholder categories— workers, local communities, value chain actors, consumers, children, and society (UNEP, 2020). The social impacts may then be reported in terms of risks for each stakeholder such as working hours, access to material resources by the community, and societal economic development. The impact categories from the UNEP Guideline are listed in the supporting information.

The impact categories are evaluated using impact indicators, which act as quantitative markers to evaluate the performance of a product/process, and are directly linked to the data inventory (UNEP, 2020). For instance, when evaluating social impacts on workers as one of the stakeholders in the clothing supply chain, Almanza and Corona (2020) used "notification of occupational accidents, incidents and diseases" as an indicator to quantify the impacts regarding workers' health and safety during the manufacturing operations. Notable, multiple indicators may be used an impact category. However, a clear separation between impact categories and related indicators cannot always be made for all the stakeholders evaluated (Luthin et al., 2023). Thus, establishing a cause-effect relationship between selected indicators and stakeholders before data collection is crucial to prevent overlap or double counting of impacts. For instance, if children are employed in the e-waste recycling industry (Umair et al., 2015), the health concerns due to toxic exposure would be considered in the impact category of workers' health and safety not under impact category of child labor since it is the unhealthy working conditions that cause the health impacts. The cause-effect relationship ensures that each indicator corresponds directly to the specific impacts experienced by relevant stakeholders. These relationships must be documented and reported in the assessment to ensure transparency while interpreting the social impacts.

The indicators related to various impact categories may be selected from the Methodological Sheets (UNEP, 2021) published as an addition to the UNEP Guidelines. These sheets provide detailed information about each impact category, the potential indicators that could be used to evaluate them, and data sources. Notedly, the list of indicators in the methodological sheets should not be considered exhaustive for any impact category. Instead, their role is to "enhance the ease and the consistency of application across different case studies" by providing a clearer understanding of impact categories in relation to the selected stakeholders (UNEP, 2021). The first methodological sheets were published in 2013 (Norris et al., 2013) and were updated in 2021 after publication of the latest UNEP Guideline (UNEP, 2021).

S-LCA is different from other social sustainability assessment tools because it is used to evaluate products systematically over their life cycle (Andrews et al., 2009). Mesa Alvarez and Ligthart (2021) reported that S-LCA is the most often used tool for evaluating social impacts of a supply chain. However, Luthin et al. (2023) report that S-LCA is not used widely for evaluating CE. They identified 104 single social indicators to assess the 'social dimension' of CE, most of which could be directly linked to the S-LCA stakeholder categories provided in the UNEP Guideline (Luthin et al., 2023). Hence, S-LCA may play an important role in evaluating the social impacts of the transition to CE.

1.4. Objective of the review

Our objective in this paper is to conduct a systematic review of existing literature by analyzing and critiquing 45 published studies on the use of S-LCA for evaluating the social impacts of transitioning to a circular economy. We investigate the geographical and industrial distribution of circular activities. Then we delve into the methodological choices made while performing an S-LCA such as the selection of system boundaries, stakeholders, impact categories, indicators, data collection, and prioritization of impacts, and report the identified social impacts in various industries transitioning to circularity. Our main goal is to identify the challenges encountered in using S-LCA, as highlighted in the reviewed studies. We also discuss solutions to the identified challenges based on the findings from these studies. By doing so, we contribute to integrating S-LCA into CE evaluation, providing insights for further development of the methodology.

2. Methodology

The methodology for the systematic review involved several steps and is shown in Fig. 1. First, a keyword search was performed using the academic databases Scopus and Web of Science ™. In this step, to locate relevant papers for S-LCA, the time frame was selected between 2009 and September 2023. Additionally, we limited the language of text to English and document type to 'articles' to include original research rather than review. Two independent searches were performed on both databases using the search strings mentioned below:

a) ("circular economy" OR recycle OR refurbish OR reuse OR recover OR circularity) AND ("social impact" OR "social performance" OR "social sustainability" OR "social benefit")
b) "Social LCA" OR "social lifecycle assessment" OR "social life cycle assessment" OR "social life-cycle assessment"

Using terms like 'recycle' and 'recover' maximized the outputs on the

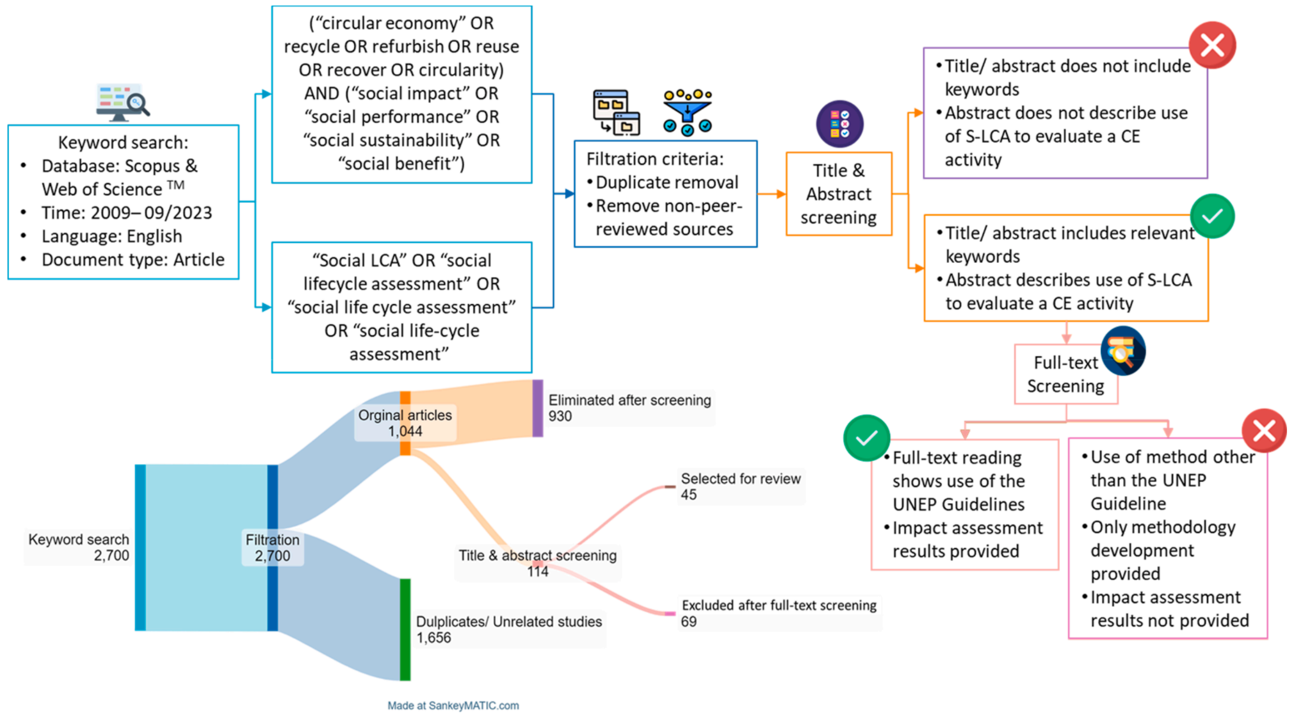

Fig. 1. Methodology for systematic review including selection and screening criteria, and a Sankey diagram to show the number of articles selected after each step.

investigated topic. Hence, in the second step we filtered the results by removing the duplicates, non-peer reviewed articles and book chapters. The third step involved screening the original articles based on their title and abstract. Here, only the papers reporting the use of S-LCA for circular economy concepts were included, narrowing the list to 114 relevant papers. Upon reading the full text of these articles, over half of them were excluded since they either focused solely on methodology development, did not base the assessment on the UNEP Guideline, or did not provide results of impact assessment leaving 45 studies. The final list of studies used for the systematic review are listed in Table S2 in the supporting information .

3. Results

3.1. Geographic spread of selected studies

The distribution of studies utilizing S-LCA across different regions or countries is provided in Fig. 2. We observed that over half of the S-LCA studies reviewed focused on the circular activities in Europe. Only 24 % studies focused on Asian countries. While South America made up 11 % studies, followed by Africa (9 %) and North America (2 %). Only one study was based on a global supply chain and did not specify a country where the product would be used.

This result could be explained by the regulatory actions undertaken by the European Union such as the new Circular Economy Action Plan

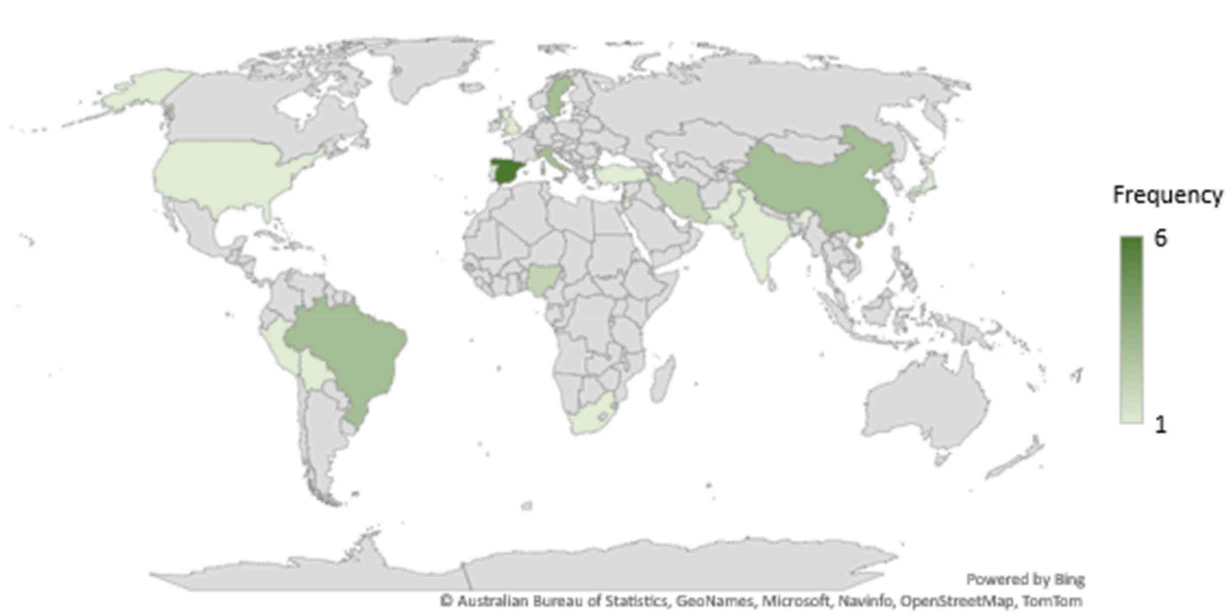

Fig. 2. Geographic distribution of 39 reviewed studies (6 studies reported regional impacts).

adopted in 2020, which includes measures to ensure a socially sustainable transition to CE (Pinyol Alberich et al., 2023). Petti et al. (2018) proposed that since the qualitative and socially sensitive data required for an S-LCA is more transparently collected and reported in the EU member states, it is easier to evaluate social impacts in the EU.

3.2. Industrial activities evaluated

The S-LCA tool is aimed at guiding practitioners towards "an assessment of social and socio-economic impacts of products life cycle" (Andrews et al., 2009). Hence, 51 % of the reviewed studies were focused on evaluating social impacts of products such as construction materials (Hossain et al., 2018), plastic bottles (Papo and Corona, 2022), clothes (Martin and Herlaar, 2021), nutrients (Andrade et al., 2022), and recovered fertilizers (El Wali et al., 2021). However, we found that S-LCA was used in the remaining 49 % studies for evaluating processes or systems that enable a transition to circularity such as waste collection systems (Aparcana and Salhofer, 2013), e-waste recycling (Umair et al., 2015), food redistribution (Bergström et al., 2020), and wastewater treatment (Opher et al., 2018).

Classifying as per the circular activity shows that 76 % of the studies are focused on energy recovery and material recycling (Fig. 3). Table S2 in the supporting information shows a distribution of the reviewed studies based on the circular activity evaluated in various industries. Recovery may be related to the conversion of municipal solid waste (MSW) into electricity (Nubi et al., 2021; Zhou et al., 2019). Whereas recycling may involve using materials within the same process or product system such as making plastic bottles using material from disposed plastic bottles (Foolmaun and Ramjeeawon, 2013; Papo and Corona, 2022) or in a different supply chain. For instance, use of lime ash, a discarded material from paper mills, for making construction materials (Simões et al., 2021). Notably, recycling does not always prevent the use of virgin materials as they must be added to meet quality or functionality requirement while making new products (Niinimäki and Karell, 2020). Hence, recycling is prioritized at a lower level in the 9R-framework while a more ambitious transition to CE should be based on extending product lifetime (Potting et al., 2017).

However, only 15 % of the reviewed studies dealt with circular activities that could extend product life like refurbishing a heritage site in Spain (Khorassani et al., 2019), remanufacturing (Martínez-Muñoz et al., 2022) and repair of infrastructure (Navarro et al., 2018; Zheng et al., 2019), reuse of leftover food (Bergström et al., 2020), and repurposing wool from sheep farms to sweater (Martin and Herlaar, 2021). The remaining studies dealt with changing the supply chain from the beginning of product life to reduce material input by changing product design. For instance, in the construction sector using bio-based components (Barrio et al., 2021) and incorporating the principles of design for disassembly in a building (Kayaçetin et al., 2022), and rethinking the supply chain for concrete procurement (Kono et al., 2018) may reduce social risks related to material procurement. None of the

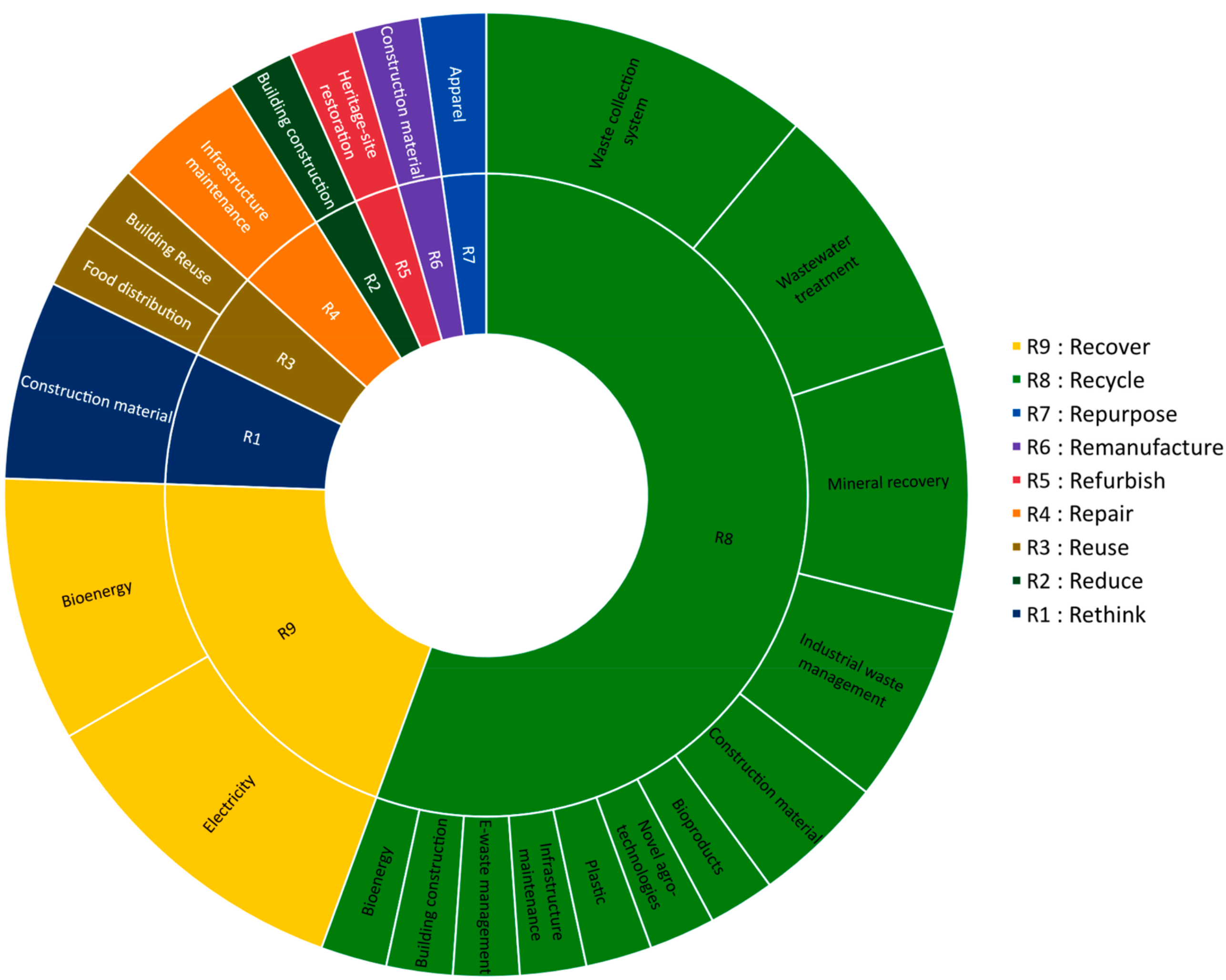

Fig. 3. Distribution of the reviewed studies as per the industrial activity [The inner distribution represents the circular activity evaluated, and the outer distribution represents industrial activities].

reviewed studies discussed the R0 or refuse pathway, which involves either not using a product entirely or providing a radically different alternative.

3.3. Role of system boundaries

A system boundary is a collection of unit processes included in the life cycle assessment (ISO, 1997). The unit processes included in the boundary are decided based on the cut-off criteria established in the goal and scope phase. According the UNEP Guideline, the cut-off criteria can be related to information availability, level of identical elements, and social significance of unit processes (UNEP, 2020).

Amongst the reviewed studies, most used a "cradle-to-gate" or "gate-to-gate" system boundary (54 % studies), which excludes social impacts arising from the use and end-of-life phases of the product. For instance, Vinyes et al. (2013) evaluated social impacts of converting waste cooking oil to biodiesel using a cradle-to-gate system boundary by including collection of waste (door-to-door or collection site) followed by transport to biodiesel production facility but the production or use of biodiesel was excluded. Similarly, Martin and Herlaar (2021) included valorization of wool followed by production of sweaters, and transport to retail facility in the boundary but excluded the use and disposal phases. Gate-to-gate system boundaries were used to evaluate social impacts occurring in the operation and maintenance phases such as for a wastewater treatment plant (Josa and Garfí, 2023; Safarpour et al., 2022; Serreli et al., 2021). The cradle-to-grave and gate-to-grave system boundaries included the use phases of a product and were reported in the remaining studies. For instance, Martínez-Muñoz et al. (2022) evaluated the manufacturing, construction, use and maintenance, and end of life of one sq-meter of bridge made from recycled construction material. None of the selected studies reported, a cradle-to-cradle system boundary, wherein materials were used in closed loop cycles at the end-of-life. The use of post-consumer plastic bottles in making new bottles may be considered cradle-to-cradle provided material losses are avoided, which is inevitable (Papo and Corona, 2022). Additionally, upstream activities were largely ignored in the reviewed studies except by Martín-Gamboa et al. (2020). They found that when evaluating electricity generation from leftover wood in the logging industry, the main social risks were during the production of the materials used, like extracting crude oil for transportation fuel and making fertilizer for growing crops, rather than when turning the leftover wood into electricity. Hence, inclusion of upstream sector within the supply chain may highlight social impacts that were not considered relevant.

The role of system boundaries is essential in determining which unit processes are evaluated for their social risks, which in turn depends on the region where the product or process is located. Several studies have highlighted this by evaluating changing regions in the supply chain. Martin and Herlaar (2021) report that the supply chains involving primarily European producers have fewer social risks than the conventional supply chains for wool that involve social risks associated with the shipping between production sites in Europe, and manufacturing facilities for the wool garments in China. Tsalidis and Korevaar (2019) also report that using circular practices such as recovering magnesium during wastewater treatment in the Netherlands may replace the magnesium imported from Russia, which has identifiable social risks.

3.4. Stakeholders, impact categories, and indicators

In Fig. 4, we have provided a hierarchical distribution based on the occurrence frequency of impact categories and stakeholders evaluated in the reviewed studies. Each rectangular box within the figure represents an impact category for a specific stakeholder, i.e., worker, consumer, local community, value chain actor, society, or children. The size of each rectangular box within the figure is proportional to the occurrence frequency of an impact category. A color coding was applied to the boxes to enhance the interpretability of the figure. Hence, a larger rectangle and a red shift implies a higher occurrence, and a smaller size and green shift implies a lower occurrence. The list of stakeholders and impact categories used in each study has been provided in Table S2.

Most studies reported impact on more than one stakeholder but only few evaluated all stakeholders from the UNEP Guideline. Out of the 45 studies reviewed here, 39 reported the impact of a circular activity on workers while only 20 studies reported impacts on value chain actors. Regarding workers, impacts related to health and safety and fair income/ minimum wages were evaluated most frequently. Other commonly evaluated impacts were working hours and discrimination. The impacts evaluated on local communities were related to their involvement in CE through local employment and changes to their living conditions.

Impact category selection while evaluating circular pathways needs to account for potential social risks, especially those arising from implementation of new technologies or supply chains. However, several of the reviewed studies reported that the UNEP Guideline did not provide relevant impact categories for this purpose as demonstrated by Teah and Onuki (2017) in their comparison of mineral-based and recycled phosphorus fertilizers in Japan. They analyzed the impact on

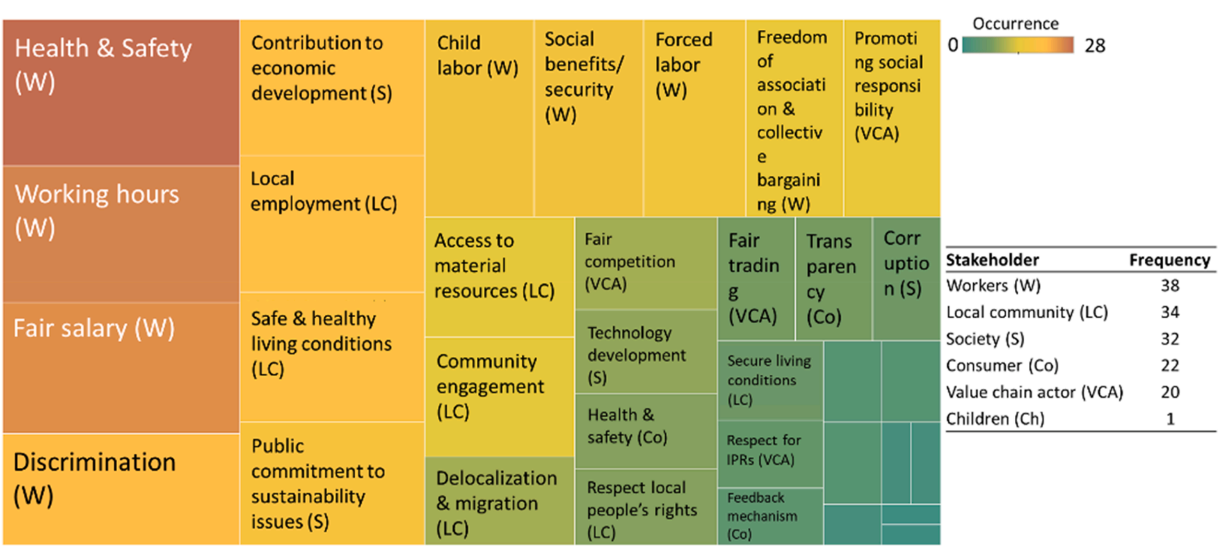

Fig. 4. Stakeholder and impact category distribution in the 45 studies reviewed is shown here as a hierarchical distribution. [The size and color of the rectangle indicate the frequency of occurrence of an impact category in all the studies selected for the review.].

farmers separately from workers through the impact category of 'livelihood' and a qualitative indicator was used to assess the risk of affording the fertilizers post introduction of recycled phosphorous. Notably, they adhered to the 2009 UNEP Guidelines, which did not include impact categories for farmers (Andrews et al., 2009). However, within the revised guidelines (UNEP, 2020), an impact category called 'Smallholders including farmers' was introduced to evaluate farmer-specific risks. Several other impact categories were reported in the reviewed studies such as 'job creation,' 'psychological working conditions,' 'training and education,' and 'occupational improvement' for workers (Foglia et al., 2021; Kayaçetin et al., 2022). Social acceptability and public opinion or customer satisfaction are used as impact categories to determine the reach of waste management practices (Yıldız-Geyhan et al., 2017). Bergström et al. (2020) used the impact category of 'food opportunities' to compare impact of food distribution systems on consumers.

The indicators for these new impact categories used were modified from the methodological sheets (Norris et al., 2013; UNEP, 2021) and published literature, or obtained through expert consultations. Specific to CE activities introduced on the farm, an indicator used by Andrade et al. (2022) was 'Cases of fatal occupational injuries in agriculture' to assess the impact category they created, i.e., 'Health and safety of workers regarding new source of damage in the farm.' Mhatre-Shah et al. (2023) created an impact category 'supply chain management' for value chain actors engaged in material recycling for construction. The indicators used quantified the compliance with the principles of 'reduce, reuse, and recycle' and changes in procurement practices. Nubi et al. (2021) created the impact category 'improved sanitation' for consumers to evaluate the impact of electricity generation from an MSW management system. The indicators they used measured the access to sanitation, change in participatory behaviour for waste sorting, and change in payments made for access to services from the new plant. The 'accessibility' of a building by consumer/ end-user could be evaluated using the indicators like 'Access to public transport and road' and 'Universal accessibility through disabled friendly features' (Lundgren, 2023). 'Livability' for local communities next to a wastewater treatment plant was evaluated by Josa and Garfí (2023) using the indicator 'Olfactory impact.'

The choice of stakeholders, impact categories, and indicators determine the extent to which social impacts can be evaluated for a circular activity. Hence, all assessments need to document and report their choices transparently.

3.5. Prioritizing social impacts

In S-LCA, weighting and scoring are optional steps in evaluating the social impacts associated with products, processes, or services (UNEP, 2020). Weighting is applied by the S-LCA practitioner and helps prioritize stakeholders, the social impact categories, or indicators based on their relative importance in the overall assessment. Scoring involves assigning a numerical value to social indicators/ impact categories to calculate a composite score representing the overall social performance of the system under study. The score can be based on the fulfilment or non-fulfilment of a pre-defined international or local social criteria (Aparcana and Salhofer, 2013). Weighting and scoring techniques must be decided in the goal and scope phase to decide how the collected data will be interpreted and analyzed during the impact assessment phase (UNEP, 2020).

In this review, studies have used several different techniques to find the relative importance (weight) of various impact categories. Tsalidis et al. (2023) used the Subcategory Assessment Method (SAM) in which the concept of basic requirements serves as fundamental criteria guiding the evaluation of social impacts by providing benchmarks for interpreting assessment results. Tsambe et al. (2021) used an organizational hierarchy of A to D, where level B implied that the organization met the basic requirement such as compliance with the regional legislation or internationally accepted criteria for determining human rights. Level A was characterized as proactive, while levels C and D implied failure to meet the basic requirements to varying degrees. Souza et al. (2022) used the Sustainable Development Goals as a baseline to score socioeconomic metrics like job growth, occupational accidents, income and education profile of workers, and gender distribution from 0 to 100, where 0 implied the worst performance and 100 implied the best performance. Subramanian et al. (2021) and Alidoosti et al. (2021) used expert judgments for prioritizing impact categories. Bergström et al. (2020) and Khorassani et al. (2019) used Maslow's "hierarchy of needs" which classifies human needs into a pyramid with 'Physiological needs' being the most important followed by 'Safety', 'Love/belonging', 'Esteem' and 'Self-actualization'. In case of food distribution for consumers, the need to have surplus food is higher for an exposed person than for a low- or sufficient income end-consumers (Bergström et al., 2020). Another commonly used technique is Analytic Hierarchy Process or AHP (Muhammad Anwar et al., 2021; Opher et al., 2018; Safarpour et al., 2022; Zhou et al., 2019). AHP involves drawing stakeholders or experts to make pairwise comparisons between the different elements of the impact assessment (like impact categories, indicators) based on their perceived importance or relevance. For example, Zhou et al. (2019) comparing impacts of converting MSW to electricity on local community may need to be prioritized based on 'concerns over the safe environment' around treatment units and 'conflicts over the land occupation' by the treatment units.

3.6. Data inventory collection

Based on the choice of indicators, qualitative and quantitative data is collected from primary and secondary sources or through a combination of both. To get more insight into the process or product under evaluation, the UNEP Guideline suggests that site-specific data is more reliable than data obtained from generic sources. Site-specific data is especially relevant because social impacts vary based on the location, and behavioral differences of companies and stakeholders involved (UNEP, 2020).

Only 20 % studies reviewed performed the assessment entirely based on primary data, which involved collecting information directly from the stakeholders identified in the goal and scope phase. For instance, Aparcana and Salhofer (2013) evaluated waste management strategies in Peru through interviews with municipalities, recyclers' associations, and non-governmental bodies. Interviews with open-ended questions could be used to encourage interviewees to reflect upon the social impacts relevant to them (Lundgren, 2023). Questionnaires requiring either detailed answers or 'yes'/ 'no' type options were also used to gather information from stakeholders (Foolmaun and Ramjeeawon, 2013). An advantage of primary data is that through interviews and surveys, the S-LCA practitioner may gather multiple perspectives at all expertise levels and from multiple stakeholders in the supply chain (Umair et al., 2015).

Secondary data collection was used by 44 % studies. It includes use of technical reports, scientific publications, statistical sources, and generic databases to evaluate social hotspots. For instance, Navarro et al. (2018) used national statistical databases to evaluate impacts of design alternatives of a bridge in Spain, and Dunmade (2019) used publicly available information to evaluate social risks of bioenergy production from food wastes in Nigeria. Several studies used PSILCA – the Product Social Impact Life Cycle Assessment database to evaluate impacts associated with rethinking construction materials (Kono et al., 2018), recycling industrial wastewater (Serreli et al., 2021), and repurposing wool into a sweater (Martin and Herlaar, 2021). Social hotspot database (SHDB) was used to identify the social risks of recycling phosphorous fertilizers in Japan (Teah and Onuki, 2017).

A combination of primary and secondary data was used by 36 % of the studies and could involve expert/ stakeholder interviews, questionnaires, and other published information. For instance, Mhatre-Shah et al. (2023) collected primary data for evaluating existing social impacts on stakeholders involved in the construction of land transportation infrastructure. But to evaluate the potential impact of adopting a circular practice, they used expert interviews. Whereas Hossain et al. (2018) used interviewed experts to identify relevant stakeholders and impact categories to assess the social impacts of using recycled materials in construction, and then used a survey for data collection from selected stakeholders. Zhang et al. (2021) used site-specific data to evaluate conversion of crop residues to electricity in China. However, the site-specific data was a combination of primary sources like surveys and secondary sources like government reports published on agriculture and electricity sector in China.

3.7. Social impacts of circular activities

In this section, we categorize the social impacts documented in the reviewed studies based on the circular activities evaluated.

3.7.1. End-of-life activities: recycle and recover

Commonly highlighted negative impacts for end-of-life activities like recycle and recovery were unregulated working hours with low wages from informal labor (Umair et al., 2015), loss of jobs due to evolving skill requirements (Mhatre-Shah et al., 2023), and the potential risk of local community's toxic exposure (Andrade et al., 2022). Whereas the positive impacts of recycling and recovery were associated with consumers and societies especially regarding access to clean water (Muhammad Anwar et al., 2021; Opher et al., 2018) and electricity (Nubi et al., 2021; Souza et al., 2022). Notably, the UNEP Guideline identifies three types of positive impacts: "(A) positive social performance that goes beyond business as usual; (B) positive social impact due to existence of product or organization and (C) positive social impact due to product utility." However, we use the term 'positive' to only imply a reduction in social risk in the evaluated CE activity.

Hossain et al. (2018) reported a combination of positive and negative social impacts on stakeholders involved in the use of recycled aggregates for pavement repair. The positive impacts were targeted towards the recyclers, producers, local communities, consumers, and the public, though natural aggregates showed higher user satisfaction due to perceived material quality. We also observed that supply chains distributed across many regions may result in mixed impacts on various stakeholders during end-of-life activities. For instance, Teah and Onuki (2017) found that recycled phosphorus exhibited fewer social risks than virgin mineral extraction, although gender discrimination remained pronounced, particularly in Japan. El Wali et al. (2021) also find in the global supply chain, promoting phosphorus recovery fails to address gender equality or reduce child labor, although it enhances water and P security and improves working conditions in some regions. Andrade et al. (2022) report that a transition to CE is likely to create more jobs in the recycling sector, which may reduce poverty and child labor provided it is accompanied with capacity building through training and education. However, several studies reported that workers and local communities have limited ability to adopt to new techniques and recovery methodologies (Foglia et al., 2021; Hossain et al., 2018).

3.7.2. Product life extension activities: refurbish, repurpose, repair, remanufacture, reuse

Strategies related to extending product lifespan, largely reported positive social impacts. For instance, Khorassani et al. (2019) reported that refurbishing a heritage site in Spain improved community engagement in conservation efforts and offered local employment, and opportunity for educational activities at society level. Martin and Herlaar (2021) reported that repurposing wool obtained as a co-product of sheep shearing activities in Sweden shifted the sweater production supply chain closer to the end user in Sweden and prevented risks associated with the transportation activities such as long working hours. Bergström et al. (2020) evaluated various scenarios for reusing surplus food across Sweden and showed that job opportunities could be created for workers not engaged in conventional markets. Additionally, it enabled vulnerable consumer groups to access food through this system. The negative consequences, particularly regarding workers' health and safety, were reported for remanufacture activities in construction sector by Martínez-Muñoz et al. (2022). The impacts could be due to new materials or construction and maintenance practices, which imbibes new risks for workers.

3.7.3. Redesign activities: reduce, rethink

Kayaçetin et al. (2022) reported the social impacts of reducing material use through a 'design for disassembly' approach. Although bio-based materials were less affordable, the prefabrication route improved worker conditions and the overall structure had positive impacts on the local community. Additionally, modular design offered more opportunity for reuse of building components. Kono et al. (2018) reported that in rethinking the production of concrete, the social outcomes were influenced by the regions of industrial activity. For example, a comparison of steel industries in the US, Thailand, and Switzerland revealed variations in factors like fair wages, forced labor, and trafficking, with the US industry performing comparatively better. Barrio et al. (2021) found that rethinking construction using bio-based materials, resulted in positive impacts for local community due to increased local employment and for society through technological development.

Based on our review, it is evident that definitive assertions regarding the benefits or risks associated with a transition to circularity cannot be made. In all the transitions to CE reviewed, while companies may not be able to change the regional situations like low levels of education, they could account for it while selecting a supply chain that goes through a particular region with identified social risks.

4. Discussion

In this section we categorize and discuss the challenges identified in the reviewed studies during various steps of conducting an S-LCA of circular activities. We also discuss potential solutions compiled from the reviewed studies that could enhance the overall usability of S-LCA. Table 1 summarizes the challenges and potential solutions for S-LCA.

4.1. Defining the system boundary

According to the UNEP Guideline, setting up a system boundary is mandatory since social issues vary based on the unit processes included in the assessment. A challenge with this step of S-LCA is lack of clarity on the unit processes to be included in the system boundary for evaluating circular activities although it is recommended to include all the socially significant steps. Most reviewed studies excluded upstream or background processes related to generation of materials that were recovered or recycled such as used lubricant oil (Tsambe et al., 2021), aggregates (Hossain et al., 2018), and lime ash (Simões et al., 2021). These studies focused on assessing the impacts starting from the collection or transportation step only unlike Martín-Gamboa et al. (2020), who included upstream impact from cultivation to identify all impacts linked with electricity production in Portugal. However, deciding to exclude upstream processes is essential for recycling or recovery activities since discarded products from one supply chain are often used to make other products or converted to energy.

There is no adequate solution for this challenge but identifying the unit processes to be included in the supply chain may be refined with iterations of the assessment and availability of information. Despite the potential social significance of an upstream unit process, the information may not always be available through primary data, especially in open-loop recycling. Hence, this information may be obtained through generic database (as shown by Martín-Gamboa et al. (2020)) or published literature and reports wherever possible. The UNEP Guideline also suggests that to ensure a holistic assessment, "the practitioner can use generic data, or complement on-site data collection with generic

Table 1
Summary of challenges with S-LCA methodology reported in the reviewed studies and potential solutions identified from the literature.

Steps of S-LCA	Challenges	Potential solutions
1. Defining the system boundary	Inadequate information about the role of upstream activities in recycling and recovery	Upstream data for recycling must be sourced from primary source, generic databases, or published literature
2. Stakeholder selection	Identifying all relevant stakeholders in the transition to CE for conducting an S-LCA	Evaluate the system boundary to find all affected parties, and use focus groups or expert consultations, published information through reports or peer-reviewed literature to identify all the affected parties in a supply chain.
3. Choosing impact categories and indicators	Available impact categories in the UNEP Guideline are inadequate for circular activities	Periodically revise the UNEP Guideline to include generic and industry specific impact categories linked with circular activities based on expert consultations
	Limited development of indicators specific to stakeholders important for CE such as consumers and value chain actors	Expand indicator list related to capture risks in use phase from product life extension and end-of-life activities
	Limited comparability of S-LCA results due to lack of standardized indicators linked to specific industrial impacts	Create generic indicators for industries by identifying the most likely risks for comparison
	No uniform benchmarking guidelines for social impact indicators due to regional differences in social impacts	Regional impacts may be evaluated against targets set using SDGs and novel technologies may be compared based on Social Readiness Level
4. Data collection	Stakeholders could be reluctant to participate in primary data collection	Stakeholders at various levels in an organization (workers/ managers) should be evaluated during primary data collection to maximize information for a unit process in the supply chain
	Transparency and veracity of the collected primary data needs to be verified	Corroborate the collected data against company and regional reports, or through site visits
	Generic databases used as secondary data sources have high heterogeneity for regional and industrial coverage	Generic data should be used for hotspot assessment followed by primary data collection for relevant processes
5. Impact assessment	S-LCA results become incomparable when transitioning from a linear to a circular supply chain due to a variation in stakeholders, processes, and organizations involved	Allocate or partition the quantifiable social impacts between various output streams of a circular system
	Impact categories may be differently interpreted based on political, ethical, and cultural context	More cases specific to CE should be published in follow up to UNEP Pilot Projects to demonstrate social risks across industries and regions.

data for some part of the value chain (often the case for background processes)."

4.2. Stakeholder selection

Many reviewed studies focused on workers and local communities only even though consumer and value chain actors are crucial in the reverse supply chain activities such as collection, processing, and reintegration of the end-of-life products into a supply chain to promote the transition to CE (Maitre-Ekern and Dalhammar, 2019; Mhatre-Shah et al., 2023). However, depending on the extent of the system boundary, it is challenging to identify all relevant stakeholders.

A potential solution may be to examine all product systems included in the system boundary and identifying all the potential affected parties as shown by Hossain et al. (2018). Tsalidis et al. (2023) consulted experts in wastewater treatment to find the most relevant impacts and classified them according to the affected stakeholders. They also used published literature to find relevant stakeholders similar to Ibáñez-Forés et al. (2019) and Nubi et al. (2021). Additionally, stakeholders may be identified through industry reports, trade associations, and with the help of focus groups or expert panels comprising various researchers involved in technology development.

4.3. Identifying impact categories and indicators

Based on the UNEP Guideline alone it is challenging to identify the relevant impact categories in several industries as shown in Section 3.4. A potential solution to this challenge that has already been identified in the UNEP Guideline is to periodically revise and expand the list of impact categories. The last update in 2020 was based on issues highlighted in the Sustainable Development Goals or SDGs (adopted in 2015) and the Guiding Principles on Business and Human Rights (accepted in 2011 by UN Human Right Commission), and inputs from S-LCA practitioners. However, the continuous expansion of the UNEP Guidelines is unfeasible. Another solution would be to identify sector-specific impact categories related to the transition towards circularity. Increased participation from experts, as demonstrated by Kayaçetin et al. (2022), could aid in identifying new impact categories and indicators. Alidoosti et al. (2021) reported a protocol where the UNEP guidelines were combined with impacts that experts commonly associated with bioenergy value chain to complete the stakeholder selection and the levels of the indicators.

However, there are several challenges with the indicator selection in S-LCA that have to be addressed since this step is "directly related to the quality of the social impact results" (Mármol et al., 2023). The Methodological Sheets are particularly lacking in indicators related to social impacts on consumers and value chain actors (UNEP, 2021). They must be expanded with development of new impact categories. For instance, to evaluate consumers, indicators are needed to quantify the impact from the use phase of the life cycle (or reuse through extended product life) and convenience for managing product at the end-of-life phase (Mármol et al., 2023).

Beyond indicator selection, the granularity of indicators is another challenge. This is shown in *Fig. 5*, where Hossain et al. (2018) evaluate workers' health and safety by looking beyond the protective equipment, accidents and policies, into the food and accommodation provided on the construction site, unlike Barrio et al. (2021). These variations in indicator choices lead to uncomparable S-LCA results within an industry despite using the same impact category. Sureau et al. (2018) suggest that indicator choices should be justified including the rationale and application. Potentially, the current Methodological Sheets could be enhanced by identifying generic and sector- or circular activity-specific indicators. While the generic indicators that may be applied to maintain comparability across sectors, the activity-specific indicators capture the nuances and complexities of social impacts. For a reliable assessment, these would need to be verified through consultation with the companies involved or verified against the national reports and databases that identify social risks for a region. For instance, in calculating the social risks of valorizing wool in Sweden, the relevant indicators from PSILCA were chosen based on consultation with the sweater making company involved in the assessment (Martin and Herlaar, 2021).

Selecting the reference points for benchmarking an impact category or indicator also limits comparability in S-LCA. Umair et al. (2015) find that benchmarking impacts based on international norms may be considered as doing neither harm nor benefit to the stakeholders.

Fig. 5. Example of indicator choices for the impact category of workers' 'health and safety' in construction sector reported by Barrio et al. (2021) and Hossain et al. (2018).

However, in the context of their assessment of Pakistan's e-waste recycling industry, companies that could meet norms should have been rated as performing significantly better than the other companies in the country. Hence, if Umair et al. (2015) benchmarked the performance against best and worst scenarios of Pakistan similar to the approach by Navarro et al. (2018) for Spain, these companies would have a positive impact. A potential solution is to present social impacts in reference to SDGs, which allows countries to propose national targets based on specific contexts that are aligned with the global goals (Cordella et al., 2023). Souza et al. (2022) evaluated electricity production from by-products of a sugar mill based on the "jobs created, occupational accidents, income and education profile of workers, and gender distribution in the workforce," which were benchmarked based on the SDGs set for Brazil. However, currently there is no harmonized way to evaluate links between S-LCA results and SDGs across various sectors (Cordella et al., 2023). The concept of social readiness level or SRL was used for comparing for new technologies by Foglia et al. (2021) and Andrade et al. (2022). It can be used as an alternative to SDGs since it provides a structured approach to assess the readiness of solutions, ranging from problem definition to societal adaptation and deployment (Innovation Fund Denmark, 2019). SRL can also guide the selection of impact categories by identifying key social dimensions or outcomes that stakeholders deem important for evaluating the success or effectiveness of sustainability initiatives.

4.4. Inventory data collection

Obtaining comprehensive and reliable information across the entire life cycle of products was reported as a challenge of the current S-LCA methodology in several studies (Barrio et al., 2021; Tsalidis et al., 2023; Yıldız-Geyhan et al., 2017). In this section, we have discussed challenges related to both primary or secondary data collection techniques.

4.4.1. Primary data

While the UNEP Guideline suggests that site-specific primary data should be used where possible to find the most reliable information about the supply chain Yıldız-Geyhan et al. (2017) found it challenging to verify the collected information. For example, informal waste pickers were often unwilling to share information regarding their waste collection practices due to the fear of its legality. Barrio et al. (2021) also reported that value chain actors were reluctant to share information due to fear of receiving poor social responsibility ratings, which restricted transparency. Some solutions available for verifying primary data could be use of company reports (corporate social responsibility reports, code of conduct, etc.). Additionally, interviews should be performed at various stakeholder levels to get multiple perspectives, as highlighted by Umair et al. (2015), and where possible site-visits should be used to observe conditions in the supply chain. To bolster the reliability of the stakeholder responses in primary data collection, a scoring system may be used, which calculates average scores from individual stakeholders, and when possible, local studies or reports could be used to corroborate the responses. To improve transparency in responses, Barrio et al. (2021) suggested that the S-LCA report could be internally fed back to the companies as recommendations and the disclosure of specific data on social aspects could be a condition for companies operating using public financing.

4.4.2. Secondary data

A challenging issue for the inventory collection from these databases is the regional and industrial heterogeneity of the data (Papo and Corona, 2022). For instance, the most recent update (at the time of writing) of PSILCA (version 3.1) includes inventory for nearly 15,000 sectors distributed across 189 countries (Loubert et al., 2023). However, there is a regional difference in the data availability. Hence, the United Kingdom is represented by 1022 industries and commodities, but the United States of America has 858 industries and commodities, whereas only 123 commodities were accounted for from China. Additionally, reliance on a secondary database alone may negate site-specific improvements (Teah and Onuki, 2017) since it ignores the effort taken by an individual site to prevent social risk (Caruso et al., 2022).

The heterogeneity regarding industrial sectors evaluated in generic databases should be reduced by encouraging more transparent information sharing between international stakeholders. Also, unit processes could be prioritized in terms of potential risks to be evaluated using site-specific primary or secondary data based on expert/ stakeholder consultations if the whole lifecycle is not evaluated due to resource or time constraints. However, measuring social impacts using S-LCA is not yet based on a consensual grounding and there is no single technique available to prioritize impacts uniformly (do Carmo et al., 2020).Based on the UNEP Guideline, materiality assessment may be performed to identify potential risks for which secondary or generic database is suitable. Though wherever possible, this assessment should be accompanied by site-specific analysis through stakeholder or expert involvement, particularly regarding novel technologies that may enhance transition to CE (Andrade et al., 2022).

4.5. Social impact assessment of CE

Comparing the social impact of novel products, particularly bio-based alternatives, with their fossil-based counterparts presents challenges due to fundamentally different production pathways (Barrio et al., 2021). Additionally, S-LCA results become incomparable when transitioning from a linear to a circular supply chain, as seen in the variation in stakeholders, processes, and organizations involved (Tsalidis, 2022; Tsalidis et al., 2023). Moreover, the transition to a circular economy may require broader system boundaries to incorporate material recovery, repair, and remanufacturing activities, which, if not adequately accounted for, could lead to inferior social performance compared to a linear system. Allocating or partitioning the social impacts between various output streams of a circular system offers a potential solution (Tsalidis et al., 2023). But the feasibility depends on the nature of social data. For instance, allocation cannot be used to assess impacts that are not measured at the product level such as discrimination, child labor, community engagement, among others (ISO, 2006; UNEP, 2020).

Aligning S-LCA methodology with circular activities requires tailored approaches and specific indicators since the extensive list of identified impact categories may be differently interpreted based on political, ethical, and cultural context (Chhipi-Shrestha et al., 2015). For instance, creation of jobs in local communities is considered a 'social benefit' during refurbishing (Khorassani et al., 2019) and building reuse (Lundgren, 2023). However, jobs created in waste collection activities often open up workers to increased health and safety risks (Yıldız-Geyhan et al., 2017). We find that the transition to CE could alter occupational landscapes in four ways. Firstly, it may lead to job creation in sectors embracing new circular business models and heightened resource efficiency (Kayaçetin et al., 2022). Secondly, certain activities may substitute others, such as transitioning from landfilling to waste incineration (Zhou et al., 2019) or recycling (Hossain et al., 2018). Thirdly, jobs could face elimination without replacement, particularly in activities like informal collection (Aparcana and Salhofer, 2013). Lastly, existing roles might redefine themselves, demanding a different skill set (Mhatre-Shah et al., 2023). However, currently the UNEP Guidelines do not provide an adequate framework to assess social risks from various circular activities.

A combination of solutions proposed in Sections 4.1–4.4 may be required to integrate S-LCA into CE assessments. Hence, further developments of S-LCA methodology would need to include specific social impact indicators aligned with CE and provide methodologies to capture multiple lifecycles. Also, the generic databases need to be expanded rapidly to include recycling and recovery practices globally and in various industries by engaging stakeholders from diverse backgrounds. Pilot projects using the UNEP Guidelines have been published by Traverso et al. (2022) and more demonstrations of similar nature but focused on CE could underscore the significance of S-LCA encouraging widespread adoption. Ultimately, a comprehensive integration of these strategies will significantly bolster the understanding of social implications inherent in circular practices across industries, driving a more sustainable and socially responsible approach within the circular economy paradigm.

5. Conclusion

This systematic review examined the current use of S-LCA in evaluating the transition of various industries to CE through an in-depth analysis of 45 peer-reviewed studies. Our findings indicate that collaborative efforts are needed between S-LCA practitioners and industries being evaluated to perform an accurate assessment. This includes identifying the system boundary encompassing all the relevant processes and affected parties, selecting (or creating) the impact categories and indicators that can identify the relevant social risks, collecting the data from site-specific and generic sources to holistically evaluate the supply chain, and accurately reporting the social impacts. There are several complexities related to using S-LCA for CE, yet it is essential for evaluating social risks in the transition to a circular economy.

CRediT authorship contribution statement

Anubhuti Bhatnagar: Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Anna Härri:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Jarkko Levänen:** Writing – review & editing, Writing – original draft, Methodology. **Kirsi Niinimäki:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Co-author is guest editor for the special issue under which this article is submitted.-KN If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

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During the preparation of this work the author(s) used ChatGPT to improve the readability of certain sections. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Supplementary materials

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