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Bridging gaps in biorefineries: The unexplored role of social dimension in life cycle assessment research

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A R T I C L E I N F O

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A B S T R A C T

This review examines the disregarded role of social dimensions in Life Cycle Assessment (LCA) within biorefinery implementation, addressing the question: "How can the inclusion of social factors in LCA improve sustainability assessments, and what are the implications of the limited Social Life Cycle Assessment (S-LCA) studies in biorefineries?" A systematic literature review was conducted using Web of Science™, focusing on studies that integrate social dimensions in LCA. Bibliometric analysis using the *bibliometrix* R-package and *VOSviewer* identified key trends, influential papers, and research gaps. Results revealed a significant gap in incorporating social dimensions into biorefinery LCA, with most studies focusing primarily on environmental and economic impacts. Limited attention is given to social aspects such as community well-being, labor rights, and social equity. Case studies that included social factors demonstrated a more comprehensive sustainability assessment, emphasizing the importance of stakeholder engagement and social acceptability in biorefinery projects. This review highlights the need for standardized social indicators and methodologies to integrate social dimensions effectively. The lack of S-LCA in biorefinery implementation reflects a critical gap in sustainability assessments. Addressing this requires developing a unified S-LCA methodology, fostering interdisciplinary collaboration, and encouraging stakeholder participation to ensure diverse perspectives are considered. Ultimately, incorporating social dimensions is essential for achieving a more balanced and comprehensive evaluation of biorefinery sustainability.

1. Introduction

To preserve the current ecosystem for future generations, the scientific community has collaborated to replace or eliminate fossil-derived compounds within the existing industrial infrastructure. This effort must extend beyond solely replacing the fuel sources used in production; it must involve strategic planning for the replacement of the various products and building blocks of industries currently reliant on fossil fuels. The introduction of biological-based refineries, i.e., biorefineries, has been suggested as one of the many avenues to resolve this issue. Biorefineries are defined as the sustainable processing of biological materials into marketable products and/or energy sources [1]. Biomass are organic materials composed by numerous types of functionalized compounds that, after extraction, refinement and conversion, can replace several fossil-based substances in various production supply lines. Furthermore, biomass sources are abundant and diverse, typically accessible locally through intentional human efforts (e.g., energy crops such as corn, sugarcane, miscanthus, etc.) or as direct outcomes (e.g., waste and byproducts including municipal solid wastes, cellulosic residues from agricultural practices or food waste) [2,3]. According to Arias et al., the demand for bioproducts is expected to reach 113 Mt/year over the next 25 years, increasing at an annual rate of 15 % [2]. The transition away from our current business model should be gradual, sustainable and account for economic, environmental and societal contexts. Generally, sustainability studies tend to focus on established metrics and methods, such as environmental and economic assessments, and assume the given project or product is sustainable if those two facets return positive results, disregarding potential social implications [3]. The evaluation of these approaches and whether they achieve what can be considered a positive effect can be performed through social life cycle assessment (S-LCA). According to the Guidelines for Social Life Cycle Assessment of Products and Organizations, developed by the United Nations Environmental Programme (UNEP), S-LCA is defined as "a methodology to assess the social impacts of products and services across their life cycle", i.e., encompassing all phases from feedstock collection or production to product obtention, distribution, etc., and, if applicable,

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disposal [4]. This assessment integrates quantitative (hard criteria) and qualitative (soft criteria) data collected from and to interested parties (stakeholders), those affected by a given product or process at any point in its life cycle [5]. It also emphasizes the importance of prioritizing critical unit processes in a life cycle (hotspots) as primary points for data collection and subsequent analysis. The term "social hotspot", as defined in the guidelines, refers to a location or activity in the life cycle assessment that significantly contributes to a specific social impact, i.e., a unit which might pose a threat to the well-being of considered stakeholders [4]. The information derived from these hotspots can be: A) transcribed onto social risk or performance via reference-scale pathways, in which indicator data is compared with a chosen reference (ex: better/worse, positive/negative) [6] or B) evaluated through an impact pathway approach, which focuses on the assessment of social impacts through the "characterization" of the relationships (correlational, causal or regression) between assessed activities and potential social impacts.

Table 1 provides a comprehensive summary of the various stakeholder categories, their respective impact subcategories and the potential indicators for use in S-LCA as outlined in the UNEP Guidelines [4].

Several challenges complicate S-LCA development, mostly due to the difficulty of quantifying "well-being" and social impact. The importance of context must be underlined; the same process under identical conditions (i.e., governmental context) may yield similar environmental and economic impacts but vary widely in social terms due to geographical location, local culture, demographics, etc. [7]. Furthermore, while quantitative indicators are arguably simple to evaluate, qualitative data is difficult to transcribe into a comparable unit. A common approach to mitigate this challenge is the application of Likert scales [8], converting acceptability/agreement into numerical scales [9]. Another challenge commonly found within this area of study resides on the fact that, unlike for the economic and environmental aspects of LCA, there is no evident method for the development of an inventory for a given functional unit (FU) in terms of social impacts. Quantitative indicators (such as the hours of work required per FU or associated monetary values based on average wages) can be used in a case-by-case basis, but these values do not translate easily into a perception of the actual social impacts [10]. This issue is generally addressed by the use of generic social information databases which serve as a tool for the identification of social hotspots throughout the product or process entire value chain. The two most commonly used databases are: the Social Hotspots Database (SHDB) [11] and the Product Social Impact Life Cycle Assessment database (PSILCA) [12], developed by NewEarth B (York, ME, United States) and GreenDelta GmbH (Berlin, Germany), respectively.

Table 1
Summary of the impact subcategories per Stakeholder category; adapted from the Guidelines for S-LCA of Organizations and Products [4].

Stakeholder categories	Impact subcategories	Possible indicators
Workers	Freedom of association and collective bargaining, child labor, fair salary, working hours, forced labor, equal opportunities/discrimination, health and safety, social benefits/social security, employment relationship, sexual harassment, smallholders including farmers	% of labors in unions, % of child employees in workforce, minimum wage/living wage ratio, % of women in workforce, % of events of harassment
Society	Public commitments to sustainability issues, contribution to economic development, prevention and mitigation of armed conflicts, technology development, corruption, ethical treatment of animals, poverty alleviation	Internal policy of commitment to sustainability issues, economic investment in the territory, policies for ethical animal treatment
Local community	Access to material resources, access to immaterial resources, delocalization and migration, cultural heritage, safe and healthy living conditions, respect of indigenous rights, community engagement, local employment, secure living conditions	Economic investment in local community initiatives, education initiatives in the area, % of employment answered by local workforce
Consumers	Health and safety, feedback mechanism, consumer privacy, transparency, end-of-life responsibility	Product compliance with health and safety standards, feedback mechanism in place, mechanism for end-of-life treatment and disposal
Value-chain actors	Fair competition, promoting social responsibility, supplier relationships, respect of intellectual property rights, wealth distribution	Legal actions related to anti-competitive behavior, existence of policies to avoid anti-competitive behavior, fair price, sufficient lead time attributed, reasonable volume fluctuations.
Children	Education provided in the local community, health issues for children as consumers, children concerns regarding marketing practices	Presence of systems promoting community and student participation, presence of education systems promoting accountability to communities

Additionally, it must be remarked that there is no universal standard for categorizing values/impacts as positive or negative social impacts. For example, job creation resulting from a system implementation may generally be viewed as positive, but if these jobs are filled by individuals from other municipalities, the impact may not benefit the local community but society at large. Failing to consider these societal aspects may lead to misattributed impacts between the various stakeholders Lastly, the development of S-LCA must be rigorously managed to prevent practices such as *whitewashing* (data misrepresentation), *redwashing* (downplaying negative impacts), *bluewashing* (implying support from international organizations) or the more commonly known *greenwashing* (overstatement of benefits). Such practices can manipulate perceptions of a product or project's social standing and should be strictly avoided to ensure an ethical, fair and impartial assessment of the system [13,14].

The primary objective of this review paper is to delve into the existing research on S-LCA within the context of biorefineries, addressing the significant gap in literature where social dimensions are often overlooked in favor of environmental and economic assessments. Utilizing bibliometric analysis, this paper identifies key trends, influential studies and research gaps in this domain. The novelty of this work lies in its comprehensive evaluation of social metrics, stakeholder categories and methodologies implemented in current S-LCA studies related to biorefineries. By systematically analyzing the limited existing studies, this review highlights the critical need for standardized social indicators and methodologies to effectively integrate social aspects into life cycle assessment. This paper not only proposes future research directions but also emphasizes the importance of including social factors to achieve a more balanced and holistic evaluation of biorefinery sustainability. Ultimately, this review aims to bridge the gap in literature by providing a detailed understanding of the current state of S-LCA in biorefineries and offering insights into how these assessments can be improved to better address social sustainability.

2. Materials and methods

2.1. Search strategy and query implementation

The literature review was conducted according to the PRISMA 2020 flowchart depicted in Fig. 1 [15]. A systematic search methodology was employed to refine the scope of the research, applying the following search strings in the Web of Science™ database in June 2024, for the period of 2015–2024:

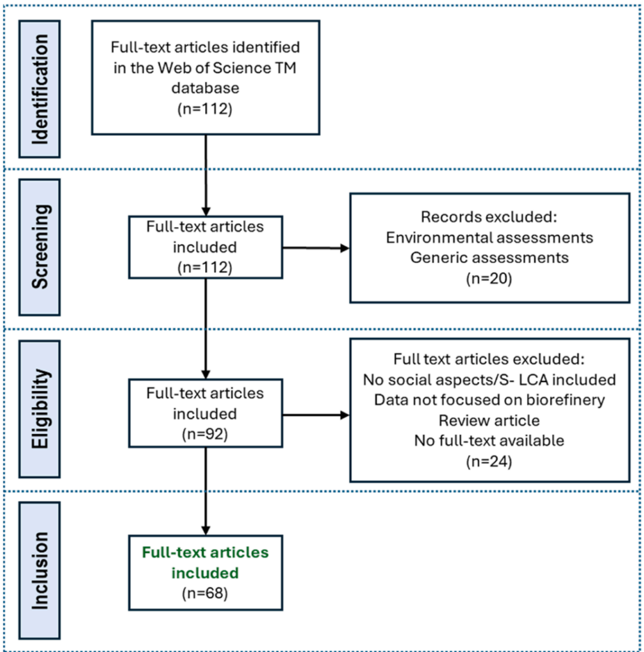

Fig. 1. Flow diagram of the literature review applied in this study (adapted from PRISMA 2020 [15]).

- *Query (a)*: ("social life cycle assessment" OR "social-LCA" OR "social assessment" OR "social analysis" OR "social impact*" OR "social sustainability")
- *Query (b)*: ("social life cycle assessment" OR "social-LCA" OR "social assessment" OR "social analysis" OR "social impact*" OR "social sustainability") AND ("bio*")
- *Query (c)*: ("social life cycle assessment" OR "social-LCA" OR "social assessment" OR "social analysis" OR "social impact*" OR "social sustainability") AND ("bioref*" OR "bioproduct*")
- *Query (d)*: ("social life cycle assessment" OR "social-LCA") AND ("bioref*" OR "bioproduct*")

Query (a) aimed to retrieve all publications related to social impact assessment research in general, while query (b) focused on publications related to the social impact assessment of bio-based systems. Query (c) specifically targeted work on the social impact assessment of biorefineries. Query (d) specifically targeted published works that used the terms "social life cycle assessment" or "social LCA" in the context of assessing biorefineries' social impact.

2.2. Bibliometric analysis

To gain insights into the research trends and patterns in the field of S-LCA as applied to biorefineries, a bibliometric analysis was conducted. Each paper was examined to extract bibliometric data including the number of citations, publication year, authorship, and the journals in which the studies were published.

For a comprehensive analysis, the open-source *bibliometrix* R-package [16] and *VOSviewer* [17] were employed using the exported BibTeX and plain text files from query (c), respectively. After a deeper analysis to identify and discard papers outside the scope, this tool facilitated the extraction and visualization of key metrics. Specifically, the keyword co-occurrence network to identify prevalent keywords and their relationships, thus highlighting core research themes and emerging topics. Trend topics provide valuable insights into the shifting focus of research and current hot topics. Additionally, bibliographic coupling allows to identify influential works and common research foundations. The analysis also encompassed identifying prolific authors, influential publications, and dominant research themes. By leveraging these methodologies, the bibliometric analysis provides a macroscopic view of the scholarly landscape, offering insights into the evolution, emerging trends, and future directions of S-LCA research in the context of biorefineries.

2.3. Systematic literature review

A systematic literature review was conducted to identify social stakeholders, social metrics, types of acquired data (qualitative or quantitative) and social categories and subcategories considered in the S-LCA of biorefineries. The steps for this review included a detailed examination of the scientific articles retrieved from the queries. This comprehensive review provided an in-depth understanding of the current state of S-LCA research in biorefineries, identifying key areas of focus and potential gaps in literature.

3. Results and discussion

3.1. Bibliographical data

The results obtained from the Web of Science™ Core Collection using different queries are summarized in Table 2. The documents retrieved cover the period of 2015–2024, highlighting the relative novelty of the S-LCA subject in the context of biorefineries. This timespan aligns with the publication date of the first version of the Guidelines for S-LCA of Products and Organizations (i.e., 2009), indicating emerging interest and research efforts in this field. Notably, a higher number of publications dealing with S-LCA or including some sort of social metrics assessment were obtained. This implies growing interest and recognition of the importance of social aspects in life cycle assessments, reflecting the increasing emphasis on holistic sustainability evaluations in recent years. It is noteworthy to highlight the discrepancy in records concerning the social impact assessment of biorefineries or bioproduct-oriented systems (query (c)). Importantly, the relevance is not limited to the terms "social life cycle assessment" or "social LCA", as evidenced by the documents retrieved in query (c), which apply assessments according to guidelines without explicitly mentioning S-LCA, as it is observed by the lower number of publications retrieved through query (d).

As depicted in Fig. 1, out of the 112 documents obtained from query (c), 20 were discarded immediately after a cursory analysis. These studies primarily focused on environmental life cycle assessment (E-LCA), optimization of biological production processes, or biomass processing, and not necessarily S-LCA or social metrics of bio-based processes. Following a thorough review, 68 studies were found to include some form of social metric or analysis. The smaller number of

Table 2
Number of publications retrieved from Web of Science™ as of June 2024 through the various queries, for the period of 2015–2024.

Query	String	Number of publications retrieved
(a)	("social life cycle assessment" OR "social-LCA" OR "social assessment" OR "social analysis" OR "social impact*" OR "social sustainability")	21,459
(b)	("social life cycle assessment" OR "social-LCA" OR "social assessment" OR "social analysis" OR "social impact*" OR "social sustainability") AND ("bio*")	3111
(c)	("social life cycle assessment" OR "social-LCA" OR "social assessment" OR "social analysis" OR "social impact*" OR "social sustainability") AND ("bioref*" OR "bioproduct*")	112
(d)	("social life cycle assessment" OR "social-LCA") AND ("bioref*" OR "bioproduct*")	23

publications is not surprising given that S-LCA and its methodologies are still an emerging field of study, especially in the context of biorefinery assessments when compared to more established fields like E-LCA or Techno-Economic Assessment (TEA). This observation is supported by the 22 publications retrieved after fine-tuning of query (c).

Fig. 2 illustrates a notable increase in the performance of such analysis over time. More interestingly, the appearance of specialized S-LCA databases on the market has facilitated a shift from simple characterization of social metrics to comprehensive S-LCA studies. The upward trend in publications also suggests that the methodologies and frameworks for S-LCA are becoming more established and widely accepted within the academic and industrial communities.

It is important to note that when the term “social acceptance” is added to the assessed queries, a significantly higher number of publications is retrieved: 25,154, 3720, and 129 documents for queries (a), (b), (c), respectively. This suggests that social acceptance is a more established area of study compared to S-LCA. However, social acceptance studies often focus on general public opinion and may not thoroughly consider the various stakeholders and diverse impact categories involved throughout the value chain, as emphasized in UNEP guidelines for S-LCA.

This disparity highlights a crucial gap in literature. While social acceptance is vital for the implementation of biorefineries and other technologies, it primarily addresses the broader societal perspective rather than the multi-stakeholder analysis provided by S-LCA. S-LCA offers a more comprehensive assessment by evaluating the impacts on workers, local communities, and other stakeholders, thus ensuring a holistic understanding of the social implications. Therefore, the bibliometric analysis and literature review focused on queries without reference to social acceptance as to maintain the specificity and relevance to S-LCA and its distinct methodological framework. This approach ensures a targeted and meaningful evaluation of the S-LCA landscape, highlighting its emerging nature and unique considerations compared to the broader and more generalized concept of social acceptance.

3.2. Bibliometric analysis

In this section, we delve into the outcomes of the bibliometric analysis conducted on query (c) after refinement, which were tuned to capture the most relevant literature pertaining to S-LCA or social impact assessment of bio-based processes and biorefineries, respectively.

The keywords co-occurrence network, illustrated in Fig. 3 and generated using *VOSviewer*, provides a clear representation of the relationships and connections between keywords in the documents retrieved through query (c), which focuses on the social impact assessment of biorefineries or bio-based systems.

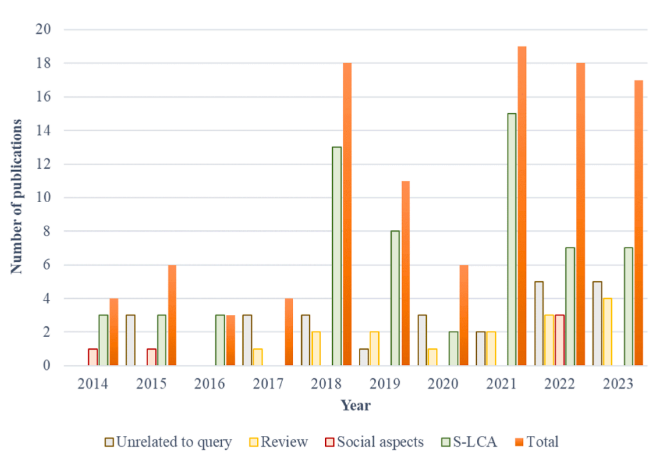

Fig. 2. Evolution of the number of publications according to query (c) for the decade of 2014–2023. Publications were sorted according to: (i) unrelated to scope (brown), (ii) review article (yellow), (iii) research article which considered a social aspect (red), (iv) research article which included partial or complete S-LCA (green) and (v) the total number of publications per year (orange).

This network offers valuable insights into the research landscape by illustrating how frequently keywords co-occur and their interconnection. Within the network, distinct clusters of keywords can be observed, namely four major clusters: “sustainability”, “biorefinery”, “biomass” and “life cycle assessment”. The latter, in particular, is a more recent cluster and interconnects with several other keywords, suggesting a common focal point among the assessed documents. It is interesting to note that keywords such as “S-LCA”, “social life cycle assessment” or “social impact” are becoming relevant keywords in the later years, revealing the increased interest in the social dimension of bio-based systems and biorefineries.

Fig. 4 provides an overview of the trending topics in the social impact assessment of biorefineries and bio-based systems from 2016 to 2023.

The term “sustainability” appears prominently from 2018 onwards, indicating its growing importance in the research landscape. “Biorefinery” and “life cycle assessment” also show consistent prominence, reflecting their central roles in this field. Emerging terms like “social impact” and “circular economy” have gained visibility, particularly from 2020, highlighting an increasing focus on social aspects and resource efficiency. “Optimization” appears from 2016 onwards and shows a notable increase in frequency by 2019, while “multi-objective optimization” starts appearing around 2016 and continues to be relevant. Terms such as “biomass”, “social life cycle assessment”, “S-LCA” and “bioenergy” show varying levels of interest over the years, suggesting specialized areas within the broader research context. The analysis of trending topics reveals a growing emphasis on sustainability, social impact, and circular economy within the social impact assessment of biorefineries and bio-based systems. The increasing frequency of terms such as “optimization” and “multi-objective optimization” highlights a trend towards more sophisticated analytical approaches. The observed trends suggest a broadening of research interests, incorporating both well-established concepts and emerging themes, thus reflecting the evolving nature of this interdisciplinary field.

The three-field plot in Fig. 5 visualizes the complex interrelations among references, authors, and keywords in the social impact assessment of biorefineries and bio-based systems. It reveals significant insights into influential references, frequently citing authors, and associated keywords. Key references such as Martinkus et al. [18], Aristizábal-Marulanda et al. [19], Souza et al. [20], Sadhukhan et al. [21], Ruiz-Mercado et al. [22], Moncada et al. [23] and Cherubini [24] are clearly pivotal in this field. Authors like C.A.C. Alzate, J.A. Poveda-Giraldo, B. Sarkar, O. Cavalett and A. Souza prominently cite these references, focusing on keywords such as “biomass”, “bioenergy”, “biorefinery”, “sustainability”, “life cycle assessment” and “social impact”. The plot highlights how authors specialize in specific topics: C. A.C. Alzate and J.A. Poveda-Giraldo emphasize “social impact”, “sustainability” and “biorefinery”, while B. Sarkar focuses on “life cycle assessment” and “bioproducts”. Additionally, the significance of “social life cycle assessment (S-LCA)” is underscored by J.A. Poveda-Giraldo and B. Sarkar, referencing UNEP’s guidelines for S-LCA. Overall, this analysis identifies foundational works and researchers driving advancements in the assessment of social impacts within biorefinery and bio-based systems, emphasizing the critical role of cited references, influential authors, and essential keywords in shaping the field.

Due to the relatively new development of the social aspect in the biotechnological area, the number of social metrics considered are usually low and their analysis relatively simple. Several studies focus on the more easily quantifiable metrics such as job generation [25,26], while some complement this data with demographic [27], wage and occupational accident data [7]. From a cursory analysis of the Top-10 articles listed on Table 3 it is relatively safe to underline the differing methodologies and parameters taken into consideration for the analysis of the social aspects. Santibañez-Aguilar et al [25], Yue et al. [26] and

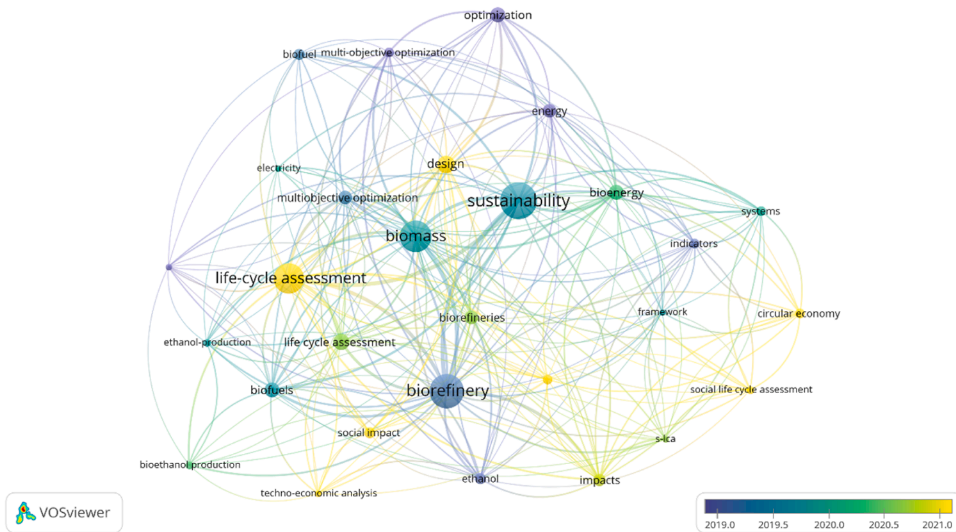

Fig. 3. Keywords co-occurrence network for documents retrieved through query (c). Map generated with *VOSviewer*.

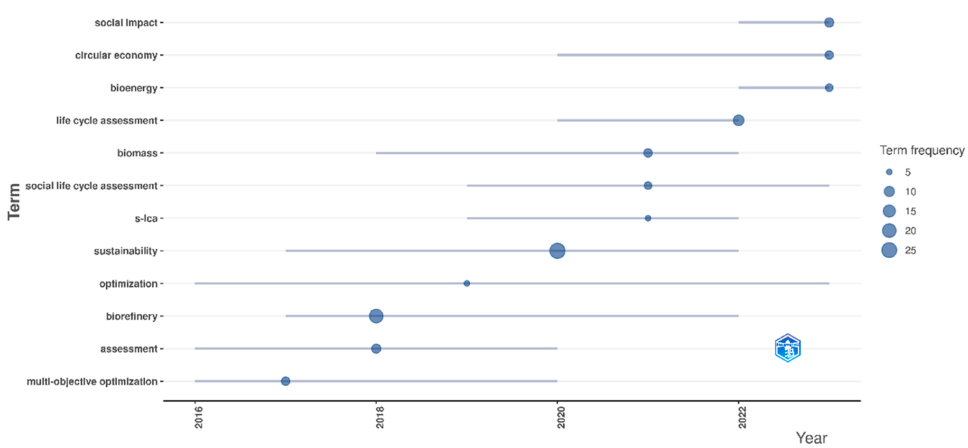

Fig. 4. Trend topics within the documents retrieved through query (c). Data analyzed and graph generated with *bibliometrix*.

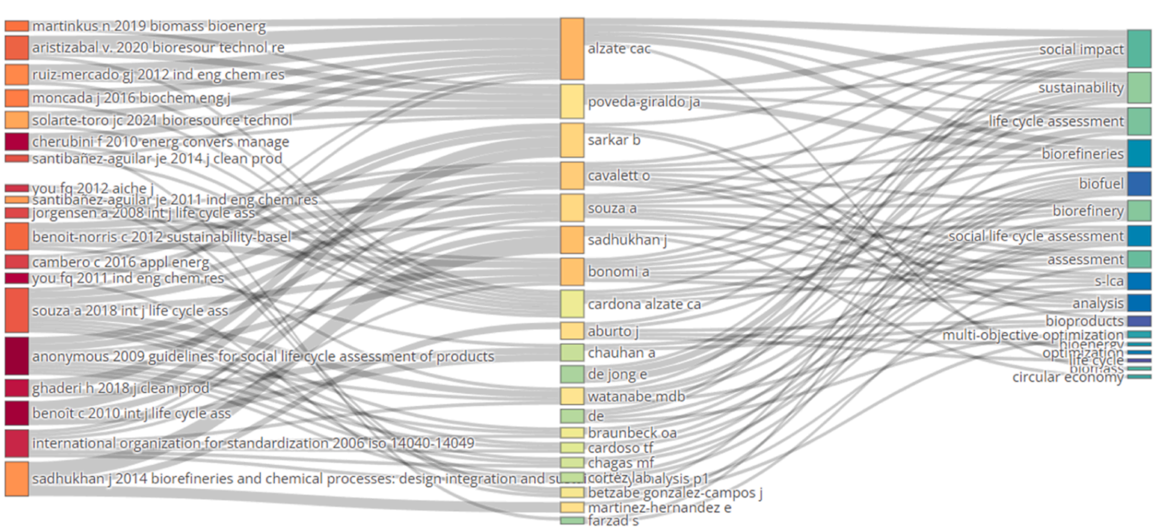

Fig. 5. Sankey diagram of three field relationships of reference-author-keywords for query (c). Data were analyzed using *bibliometrix*.

Table 3
Top-10 most influential research papers (excluding reviews) on S-LCA or social impact assessment of biorefineries/bioproduct-oriented systems, ranked by number of citations. Data retrieved through query (c) as of June 2024.

#	Title	Authors	Year	Social metrics considered	Database used	Citations	Ref.
1	Optimal planning and site selection for distributed multiproduct biorefineries involving economic, environmental and social objectives	Santibañez-Aguilar, JE; González-Campos, JB; Ponce-Ortega, JM; Serna-González, M; El-Halwagi, MM	2014	Number of jobs generated	NA	205	[25]
2	Sustainable Design and Operation of Cellulosic Bioelectricity Supply Chain Networks with Life Cycle Economic, Environmental, and Social Optimization	Yue, DJ; Slivinsky, M; Sumpter, J; You, FQ	2014	Number of jobs generated	NA	98	[26]
3	Novel macroalgae (seaweed) biorefinery systems for integrated chemical, protein, salt, nutrient and mineral extractions and environmental protection by green synthesis and life cycle sustainability assessments	Sadhukhan, J; Gadkari, S; Martinez-Hernandez, E; Ng, KS; Shemfe, M; Torres-Garcia, E; Lynch, J	2019	Labor rights and decent work, Health and safety, Human rights, Governance, Community infrastructure	SHDB	89	[31]
4	Towards sustainable production and consumption: A novel DEcision-Support Framework IntegRating Economic, Environmental and Social Sustainability (DESIRES)	Azapagic, A; Stamford, L; Youds, L; Barteczko-Hibbert, C	2016	Direct employment, total employment, worker injuries, human toxicity potential (excluding radiation), total human health impacts from radiation, fatalities due to large accidents, amount of imported fossil fuel potentially avoided, diversity of fuel supply mix, fuel storage capabilities (energy density), use of non-enriched uranium in a reactor capable of online refueling, use of abiotic resources (elements), use of abiotic resources (fossil fuels), volume of radioactive waste to be stored, volume of liquid CO_2 to be stored.	NA	79	[28]
5	Economic, environmental, and social impacts of different sugarcane production systems	Cardoso, TF; Watanabe, MDB; Souza, A; Chagas, MF; Cavalett, O; Morais, ER; Nogueira, LAH; Leal, MRLV; Braunbeck, OA; Cortez, LAB; Bonomi, A	2018	Number of jobs generated, number of occupational accidents, average worker wage	NA	50	[29]
6	Social life cycle assessment of first and second-generation ethanol production technologies in Brazil	Souza, A; Watanabe, MDB; Cavalett, O; Ugaya, CML; Bonomi, A	2018	Number of jobs generated, number of occupational accidents, average worker wage, % women in the workforce, education degree profile.	Hybrid SLCA model (Brazil-focused)	46	[27]
7	Environmental and social life cycle assessment to enhance sustainability of sugarcane-based products in Thailand	Prasara-A, J; Gheewala, SH; Silalertruksa, T; Pongpat, P; Sawaengsak, W	2019	% farm owners (with no conflict with land rights, satisfied with net income), % workers (reporting satisfied with wage, 1 day off per week, working hours aligned with regulations, overtime work payment, freedom of collective bargaining, no discrimination, no accidents in past year, having protective equipment), net income, worker wage, number of jobs generated	PRé Consultants B.V. 2019	41	[7]
8	Management of animal fat-based biodiesel supply chain under the paradigm of sustainability	Habib, MS; Tayyab, M; Zahoor, S; Sarkar, B	2020	Economic impact, number of jobs generated	NA	37	[32]
9	Sustainable biodiesel supply chain model based on waste animal fat with subsidy and advertisement	Singh, SK; Chauhan, A; Sarkar, B	2023	Economic impact, number of jobs generated	NA	36	[33]
10	Social life cycle assessment methodology for evaluating production process design: Biorefinery case study	Cadena, E.; Rocca, F.; Gutierrez, J.A.; Carvalho, A.	2019	36 quantitative indicators		30	[34]

Azapagic et al. [28] follow a similar approach, in which the indicator “job generation” is modelled with basis on empiric data and discussed against economic and environmental impacts while authors such as Cardoso et al. [29], Souza et al. [20] and Prasara-A et al. [30] focus their efforts on the analysis of Stakeholders closer to the foreground system (*Workers*). Of particular interest in this list is the article by Cardoso et al. [29], a study which details carefully the influence that different technologies of sugarcane production, in particular manual and mechanized harvesting, have on the social aspects of sustainability when considered under a model of vertically integrated production.

The initial queries, along with the corresponding entries and bibliometric analysis, did not capture the full range of work relevant to this study. A brief review using an additional database (Google Scholar) identified a total of 43 articles, 25 articles of which were not present in the original results. Although these articles were not included in the bibliometric analysis, several were considered in the subsequent overview section.

3.3. Overview of document selection and key findings

As previously mentioned, the Guidelines for Social Life Cycle Assessment of Products and Organizations [4] provides various avenues for analysis, considering the various indicators which can be considered and the manner these can be quantified or evaluated. It does not, however, make any number of indicators obligatory, allowing practitioners to pick and choose which indicators and sub-categories are important to the production process under assessment.

The stakeholder categories of *Workers* and *Local Community* were

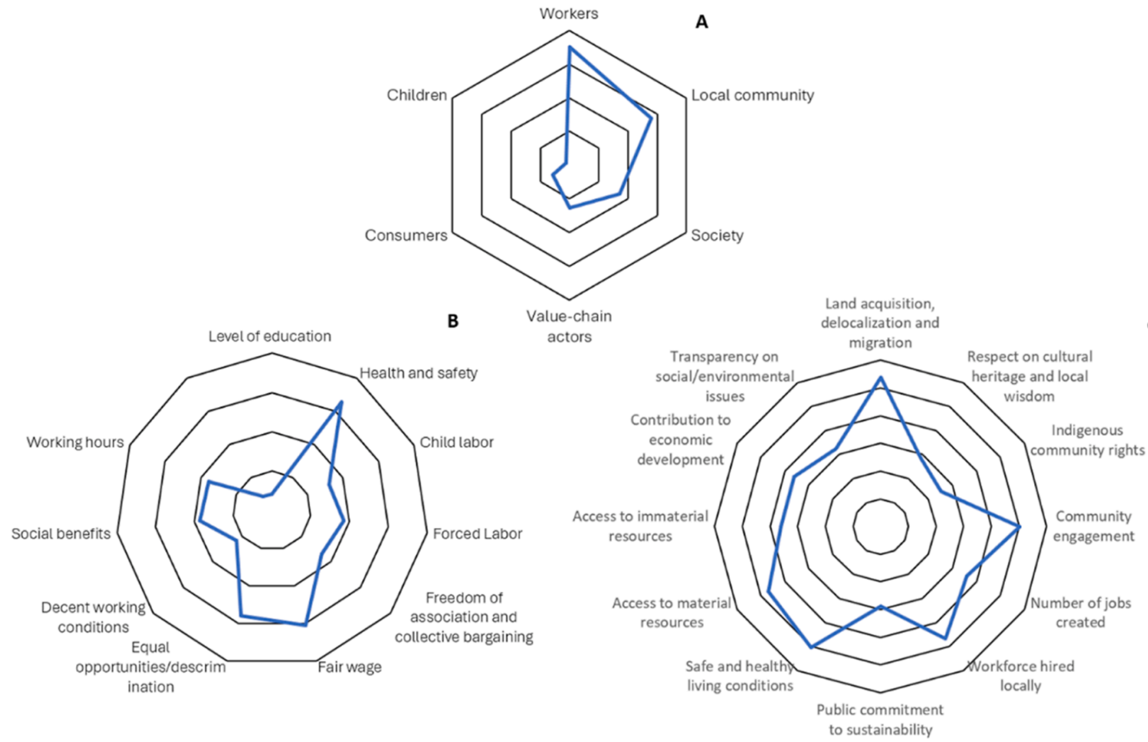

Fig. 6. Radar chart representing the (A) assessed stakeholders, (B) subcategories assessed for the stakeholder "Workers" and (C) subcategories assessed for the stakeholder "Local Community" throughout the bibliographical analysis.

considered for analysis in 35 % and 28 % of studies, respectively (see Fig. 6). Notably, when it comes to the categories chosen, there seems to be a distinct prioritization for more easily quantifiable categories and indicators. *Workers* were predominantly evaluated through categories such as health and safety (17 %), fair wage (15 %) and equal opportunities and discrimination (14 %). These subcategories are mainly transcribed by the indicators number of accidents in labor context, average wage and % of women in the workforce, respectively, all of them indicators easily quantifiable by the evaluated entity or the practitioner. In a similar manner, studies focusing on the *Local Community* prioritized indicators related to job creation (16.5 %), Delocalization and Migration (11 %), Community engagement (10 %) and Safe and healthy living conditions (9 %). It is important to note the analyzed studies consider employment to be transcribed by one of two subcategories, job generation and local employment. While similar in absolute terms, they do not impact the *Local Community* in the same manner. This subject is discussed in detail in the appropriate section below. The stakeholders *Society* and *Value Chain Actors* are considered in significantly a lesser number of studies, averaging approximately 15 % of the evaluated body of work. Societal analysis often relies on assessment databases, which may lack contextual data. Common indicators used in these analyses include elements that are challenging to quantify, such as "Corruption" (14 %) and the "Transfer of knowledge and technology" (12 %). Interestingly, there is often a transfer of indicators typically associated with one stakeholder to another. A very common example during the preparation of this study was the use of the indicator "Public commitment to Sustainability", often shared between *Local Community* and *Society*. This review found that studies do not typically consider the Consumer, as biotechnology or biorefinery systems are not typically as advanced as to warrant or even make possible the dissemination to the public and subsequent analysis of the impacts. When studied, there is a clear disposition to guarantee the "Health and Safety" of the Consumer as well as need to estimate the acceptability of the product. Finally, as a last remark, the stakeholder category *Children* featured solely in two of the reviewed documents, possibly either due to its recent introduction in the UNEP's Guidelines [4] or the perceived lower social impact on this stakeholder within biorefinery operations. Further analysis of these findings will be elaborated in the following section.

3.4. In-depth stakeholder analysis in S-LCA of biorefineries

3.4.1. Workers

The predominant approach in social analysis often centers on economic aspects, especially those concerning the stakeholder category *Workers*, aspects often easier to quantify, classify and compare. According to the retrieved data, "fair wage" and "health and safety" are the subcategories most often considered (approximately 32 % of total assessed indicators), likely due to their relative ease in being transcribed into mathematical values and compared to references. Common quantified variables related to fair wage include comparisons between average paid wage (APW) and the living wage (LW) or minimum wage (MW) of the country in which the production is located or, more appropriately, the relation of the minimum paid wage with LW or MW (fair wage category) [7,35–37]. The analysis of the referred variables has clear limitations. MW, often set by governmental bodies, can tend to be detached from the immediate reality of the country, especially during times of economic unrest [38]. Additionally, the parameter LW, which transcribes the cost of goods and services required for a given standard of living, might not translate into the real financial necessity as it varies according to the number of individuals considered, household necessities and societal context [39]. As an example, Aristizábal-Marulanda et al. [19] compares the LW in the production location (Colombia) to the south American LW, concluding that the wages adopted by the company have medium risk of not being sufficient for the survival of standard familial units. This comparison alone is inadequate as it fails to consider whether the AW provided by the company is sufficient for an individual, or account for the possibility of a two-person household (and their dependents) having an additional source of income. It also considers completely different financial contexts, which is generally a problem when using more generic, country-wide parameters. Solarte-Toro et al.

[40] identified a clear disparity between the MW and LW (ratio of 0.72) in the Colombian territory and analyzed how the ratio increase would impact the economic viability of the biorefinery (reflected through the analysis of the NPV values). According to the referred study, a biorefinery must achieve a MW/LW ratio of at least 1 to be considered as having a good social performance. It is important to underline that the value of 1 merely considers that the family unit has enough financial resources to cover the basic necessities of modern living (e.g., acquisition of food, technology, transportation, living space, clothing) but does not go beyond it, disregarding what can be considered unnecessary expenditures or luxuries. The difference in social impact when considering a sufficient salary in comparison with a good salary and which % of increase would be acceptable should be highlighted and implies a deeper degree of information from the workers. At this point a new qualitative indicator can be introduced into the analysis, the concept of worker satisfaction (%) [7]. Prasara-A et al. (2019) [30] compared AWP and MW of Thailand while conjugating it with the % of workers satisfied with the received wage in the context of a sugarcane biorefinery, underlining that for the social performance to be acceptable, all workers must be satisfied with the salaries received. Of the studied literature, only Prasara-A et al. [30] considered this parameter, questioning the workers at the farm and factory levels. A higher degree of satisfaction was denoted at the sugar processing level, reaching slightly lower percentages at the farm level. This result is consistent with the lower salaries usually associated with manual agricultural work [41] and the fact that these employees are paid per amount of biomass cut, instead of an hourly wage. This study also identified a 100 % worker satisfaction when related to factory wages, usually associated with a higher degree of required specialization and, consequently, higher wages. Interaction with the involved stakeholders, whether through inquiries or direct interviews, permitted the introduction of context into the quantitative data and a greater appreciation of possible social impacts. As with all surveys conducted, and in order to guarantee study significance, this survey effort must be conducted in an anonymous and independent form or risk the introduction of bias in obtained responses as to avoid problems with company management. This is especially necessary when the assessed group is smaller and easier to identify through given replies.

The variable working hours is used as an indication of increased of accident risk, due to more time present in the workplace [37], and a decrease of the worker general well-being, as free time for other pursuits and responsibilities is significantly reduced. The general quantification related to this subcategory focused on the direct calculus of the necessary hourly labor for a given task to be performed by the available workforce [36]. Studies such as those performed by Giraldo et al. [42] and Solarte-Toro et al. [40] include extraordinary working hours related to maintenance activities, downtime and resting time in the calculation [42,43]. This consideration is necessary, as increased activities imply either more available workforce or the introduction of additional extraordinary hours and an associated increased social impact. The reference for the comparison of this parameter is not linear. Some studies, like Prasara et al. [30], consider that this variable translates a positive social performance if the social standards are met or exceeded. However, maximum weekly working hours are generally defined by national legislation, with free days or extraordinary working hours being allotted according to the hiring company, i.e., a positive impact should not be inferred merely by attaining the bare legal minimum. In general, work hours beyond the legal maximum and obligatory extraordinary hours as to achieve a given production quota are generally considered bad social practice while the introduction of varying scheduling and flexible work hours are suggested as good measures to improve the social performance of a given endeavor [44]. The evaluation of the working hours subcategory can also be used as a tool for the assessment of the impact of a given change in the production system on its workers. As an example, Du et al. explored the reduction of working time facilitated by the introduction of mechanical as replacement of the manual harvesting of sugarcane [45]. The authors registered a reduction of the necessary working hours for the completion of the referred task and of the intensity of the physical labor required, but also a significative reduction of the number of necessary workers. The indicator serves then as a measure of the quality versus the quantity of the procured work.

Health and safety is the second most evaluated subcategory in biorefinery S-LCA studies [27,29,35,46–48] with the main indicators considered being the quantification of work accidents (fatal and non-fatal) per annum and the existence of available in-house health and safety policies. Less common indicators such as DALY (Disability-adjusted life year) due to indoor and outdoor air and water pollution and local mortality rates and disease burden attributed to indoor smoke are indicated by Serreli et al. [47] and Mattioda et al. [49], respectively. These indicators serve as a measure of long-term consequences of the industrial activity under assessment. Josa and Garfi take a slightly different approach, focusing on the production process itself [50]. In their 2023 study, the authors propose the use of microalgae for wastewater treatment and resource recovery. As to ascertain the social performance of the system in relation to “health and safety”, the types of equipment belonging to the industrial facility were identified and attributed hazard and severity values according to seven possible causes of injury: “oxygen deficiency, physical injuries, toxic gases and vapors, infections, fire, explosion and electrocution”. Risk was defined as the sum of the product between the hazard and severity values for each piece of equipment. While this method does not allow comparisons with other studies, it does permit comparison between the various scenarios within the same production facility. For example, the authors compare the use of urban wastewater and standard growth media for microalgae culture. As expected, the use of wastewater has a decidedly higher impact on the health and safety of the workers, probably due to the possibility of infections or the increased amount of necessary operations for its processing, leading to a more prolonged exposure to risk. This subcategory serves as an example of the limitations of the social LCA. While the quantification of work accidents implies diminished work security (negative impact) and the existence of in-house safety policies points to the existence of prevention actions as to protect workers (positive impact), there is no comment made about the quality of this information and the actual impact upon workers. The existence of in-house safety policies does not imply the existence of safety equipment or the degree of application of the referred policies. This study serves to underline that indicators can be tailored to the study in question, taking the context into consideration as to design “in-house” indicators which can then be used for comparisons between systems with a high degree of similarity. The same indicators can be used in assessments of other wastewater treatment methods.

The subcategory “equal opportunities/discrimination” seems to be analyzed through the superficial evaluation of gender inequality. Several studies account for the events of discrimination in relation to women but rarely mention other types of discrimination (racial, religious, sexual orientation), distinguish between types of harassment [47,49,51,52] or consider the quantification of harassment incidents. Exceptions found in the body of work are, for example, the consideration of level of disability by Vinyes et al. [53], age and minority composition by Valente et al. [35]. As expected, not all information can be included in a study and there is a fine line between making a simple or onerous questionnaire to the assessed stakeholder to respond to but information such as percentage of minorities in leadership positions, number of harassment incidents and quantification of minorities would be a helpful addition. As it stands, the quantifiable parameters related to this subcategory primarily center on the percentage of women in the total workforce and the paid wage gap between men and women. As an example, Souza et al. [20] was able to discern that the distinct difference between the fraction of women in the workforce and its possible relation between the amount of physical labor involved in the system (farm work versus mechanized/introduced automation). The low presence of women workers at the farm level might not transcribe the inability to perform said work but possible discrimination policies during hiring. Of the studies selected for this review, only Valente et al. [35] accounts for the quantification of minority members and hired age groups while Souza et al. [20] mentions the education degree profile as an indicator. Prasara-A et al. (2019) quantifies the percentage of events of discrimination reported as an indicator but does not comment if there are venues for these reports, possibility of reprisals due to discrimination reports or the cause behind these events [30].

The subcategories “child” and “forced labor” are also consistently considered for study, serving as a mirror of the current landscape of the workforce. The Handbook for Product Social Life Assessment defines both categories as “work that deprives children of their childhood, their potential and their dignity, and is harmful to physical and mental development” and “all work or service which is exacted from any person under the threat of any penalty and for which the person has not offered himself/herself voluntarily”, respectively [54]. The analysis of biorefineries systems considered in this document focuses on the existence of both forms of work within the boundaries of the system [35] or the risk of these taking place [45]. Forced labor is vastly considered to be illegal and its mere existence has negative effects. Hence the use of the indicator “incidence of forced labor” seems to be adequate for the type of analysis undertaken in biorefinery S-LCA. The child labor indicators, however, require a finer analysis. According to Jørgensen et al. child labor should be further characterized through indicators such as school attendance, impact on schooling outcomes or exposure to hazardous work since the mere incidence of child labor does not imply obligatory negative nor positive impacts [55]. The authors argue that while the objective of related documentation is the elimination of all forms of child labor [56] the context is once again vital. In certain poor economic contexts, families might rely on child labor to supplement their income, and a complete prohibition could push children into dangerous or illegal work. Sadhukhan et al. suggests this very same possibility related to the development of macroalgae based systems, where the relative easiness in macroalgal culture might be used as an additional source of income [31]. In the context where child labor cannot be abolished, Fontes et al. underlines that if legal, the companies should ensure the children attend school appropriately combined with a manageable amount of work hours, developed during the day. Additionally, though this latter condition is a commonality to every worker involved in the analyzed system, the workplace should have adequate safety measures [54].

In conclusion, most studies focused on quantitative indicators, especially financial parameters, as these are easier and faster to obtain from the involved structures compared to surveys or direct interviews with the workforce. These are often used in biorefinery studies as tools to predict the quantity of worker units to be employed, prioritizing legal minimum or living wages as baseline for reference. Demographic data use was limited and commonly applied as indicative of possible discrimination issues, forced and child labor. There was a distinct inability to reach the stakeholder directly, in its majority due to the low technology readiness level (TRL) of the production system under assessment, and therefore, a lack of data related to the satisfaction of the worker groups in relation to the biorefinery operation. The regional context was not typically considered, as its detailed assessment requires more extensive work that may not be feasible for smaller study groups that view social assessment as supplementary to environmental and economic studies.

3.4.2. Local community

Local Community can be defined as “individuals (…) that maintain intergenerational connection to place and nature through livelihood, cultural identity and worldviews, institutions and ecological knowledge” [57]. This information is not easily transcribed into a practical context, being a nebulous description of the surroundings of the production facility but without limits to sample size (number of considered inhabitants), territory size (considered territory radius) or legislative classification (village, city, municipality). The principal indicator considered for this stakeholder was “job generation”, accounting for 45 % of the total number of researched indicators. This category was generally equated with the term “local employment” (generation of employment answered by the local workforce) even though their impact is dissimilar. Local employment directly affects community members, while job generation may lead to indirect positive impacts such as new population settlement in rural areas or increased commercial activity. Aristizábal-Marulanda et al. [19] and Padilla-Rivera & Merville [58] are the only studies in the analyzed documents that mention this distinction. The first study quantifies both indicators, but due to the theoretical nature of the model, the values obtained were not compared or discussed. The works by Panoutsou et al. and Garcia-Vallejo et al. focus solely on the indicator “job generation” but underline that, as the projected biorefineries are to be located in rural areas, this constraint might lead to a locally employed workforce [59,60]. The remaining studies focus exclusively on job generation [18,27,29,50,61–63]. The consensus was that creating labor opportunities positively affects the community, without further comments on work quality or related financial conditions. Prasara-A et al. (2019) analyses this indicator in conjunction with the fair wage indicator (stakeholder category *Workers*) in a sensitivity analysis [7]. The relation between minimum and living wage with the number of jobs generated is discussed in Section 3.4.1 but it is important to underline that a lower wage which does not account for the cost-of-living attracts cheaper labor, generally associated with worse living and working conditions. According to Shandro, the absence of basic amenities, job security and suitable working conditions negatively impacts the overall well-being, health and safety of the community [64]. Therefore, while the generation of jobs is of utmost importance, these must be safe and fair to guarantee a beneficial impact on the local community.

Approximately 23 % of the analyzed studies refer to the subcategory “Access to material resources”, often discussed as the negative impact on the available supply of a given resource by the facility and the indirect impact that this event might have on the local community and territory in general [36,42,47,49,59]. This negative impact might be caused by the expanded use of the resource (ex: increased energy use) or its deterioration by the activity of the industrial activity (ex: increased emissions into land or water). For instance, several studies expressed this category through the indicators “access to industrial water” and “access to renewable water”, quantifying both according to the ratio between the water usage in the facility and the total available water and total available renewable water (country), respectively [36,42,63]. In a biorefinery setting, industrial water use is mainly related to cooling, pretreatment stages or other reactions and particularly hard to optimize and minimize [63]. Higher ratios of both indicators might have an impact on the volume of available water for public consumption and, consequently, in the market value of said resource [65]. Garcia-Vallejo et al. [60] compared the water usage of the projected biorefinery to the water use by the industrial sector under assessment (avocado production) and concluded that the new addition does not significantly impact water demand for the sector. Therefore, the implementation would likely not impact local water access [60]. The indicator “energy use” is discussed in the same manner [47,60,63], comparing the energy expenditure of the project with the national energy demand as to access variations in necessary supply and energy price. In the case of small-scale biorefineries, the increase in local energy consumption caused by implementation was not significant to affect demand [60]. Three studies consider land use through the “Extraction of biomass” indicator (in relation to area). Josa and Garfi relate biomass extraction to area and population but lack specific units to be used [50], while Serreli et al. discriminate the analysis of the dimensionless value [47]. Panoutsou et al. compare yield among various crops, suggesting that higher yields require less cultivation area or have a higher amount of extracted value [59]. Another study compares the area needed for crop production against total crop area, showing that a biorefinery based on *Pinus patula* for ethanol, furfural, vanillin, vanillic acid, and energy production poses low social risk due to its low indicator value (27 %)

[42]. The chosen indicators in these studies lack reference scales for easy evaluation, making it difficult to measure their positive or negative impact.

In addition to this information, the analysis of access to immaterial resources is recommended, particularly by Solarte-Toro et al. [40]. Biorefineries are generally linked to sustainability ideals and modern production practices. Indicators such as “number of education events directed at the population” and other formative initiatives could demonstrate that the project aims to educate and enhance acceptance of these types of initiatives. This topic can also be expressed through the implementation of sustainability policies, reflected by the subcategories “public commitment to sustainability” and “safe and healthy living conditions”, with indicators like relative contribution to NOx emissions and GHG emissions [36], sanitation coverage [47], relative pollution levels of the country, or drinking water coverage.

The previous section highlighted a preference for indicators that could be easily calculated by the study groups, primarily focusing on financial parameters that did not necessitate interaction with the local community. The extended timeline required to include this stakeholder, along with the challenges in reaching various community members, typically surpasses the duration of scientific projects, rendering them less practical as tools.

3.4.3. Additional stakeholders

The stakeholder categories *Society, Consumers* and *Value Chain Actors* are frequently overlooked in the analyzed body of work, while *Children* are barely referenced. The stakeholder society in biorefinery S-LCAs shares several of its indicators and subcategories with those mentioned in Section 3.4.2. (Local community). The methodology is comprehensible since the primary distinction between the two stakeholders lies in their scale and proximity to the production point. Gonzales-Garcia et al. mention the analysis of the subcategory “contribution to economic development” and “public commitment to sustainability” [52]. A national public commitment to sustainability, supported by policies, action plans, financial incentives, and legislative flexibility for the inclusion of new technologies or initiatives, is challenging to develop through smaller-scale projects. However, their results can be used as a basis for larger-scale decision-making [50], influencing governance directly [66]. The effect of the assessed sector on the overall economic development of a given territory caused by investment, job creation, incentives to education or training is also of utmost importance [47]. In the case of biorefineries, projects related to renewable energy systems and waste valorization further contribute to the energetic independence of society at large or the improvement of its environmental performance through the synergy of industrial streams. The impact can be direct, through the creation of value (% of growth domestic product generated [12]), or indirect, through the development of technology, incentivizing national production, reduction of energy dependency, etc., and evaluated through the public perception of the population [47]. Additional subcategories such as “local employment” or “quantification of work accidents” are also referred but, as they are related to the previous stakeholders, were discussed in Section 3.4.1 and 3.4.2 [46,47]. Serreli et al. also consider the subcategory “Contribution to economic development” through the analysis of the indicator “high level of literacy” [47]. A higher level of literacy in labor pool may enable capacity for specialized work and ease the development of technologically advanced enterprises such as biorefinery systems. It may also result in higher wages, positively impacting both local community and society. On the other hand, lower literacy levels can limit local employment, leading to less technological production or reliance on emigrant labor. It may also increase unspecialized labor in poorer areas, incentivizing school abandonment and maintaining the *status quo* [67]. Introduction of training courses or in-house educational incentives could help address this issue and enhance positive impact. Nevertheless, this indicator is measured nationally and may not reflect the specific circumstances of the region receiving the production facility.

The stakeholder group *Value Chain Actors* is considered in approximately 13 % of the studies reviewed. The main goal of social assessments for this group is to ensure the fair distribution of financial or material value through the production supply line. In biorefinery assessments, it is crucial that the revenue from the refined products is not only concentrated in technological subsystems (i.e., biomass conversion and refinery into the product of interest) but reaches the biomass origin stage [7,59]. Corruption, anti-competitive behavior and market monopoly can negatively impact value chain actors [47]. Issues such as insufficient lead time, increased stock demands, or lack of available stock can harm biorefinery operations and the relationships among chain members. Therefore, these factors must be identified, assessed and evaluated.

The principal interest for the *Consumers* in relation to a biorefinery operation is the guarantee of safety and benefits of the final product. The questions generally posed might be related to the environmental sustainability of the production or process, additional health benefits when compared to those already established by the competitor, quality, performance, safety concerns and cost increase [52]. Increased transparency can enhance consumer security and acceptance, which may be communicated back to the producer via feedback mechanisms [46,47]. When evaluating the social behavior of biorefinery products, it is crucial to consider valorizing waste streams to improve environmental performance. Josa and Garfi highlight potential health hazards related to using residues like wastewater in food production, which may reduce public acceptance [50]. Although society might be interested in residue use, there might be reluctance if associated with food sources. Ensuring quality, safety evaluation, information and transparency is essential to increase public acceptance [50,68].

A similarity among the analysis of these three stakeholders was the authors’ reliance on generic databases such as SHDB and PSILCA. The specific subcategories are challenging to quantify, and achieving a significant study population percentage is beyond the scope of smaller study groups. Additionally, value-chain actors exhibit varying levels of transparency regarding data related to corruption and value distribution, making them a less reliable source of information. Social information databases facilitate this analysis and reduce the timeline for data retrieval at the expense of possible contextual influence.

The recent inclusion of the stakeholder *Children* in the UNEP Guidelines [4] results in limited mention in this body of work. With this recent addition, there may be interest in relocating the subcategory “Child Labor” from the *Worker* analysis. One of the subcategories related to the newest stakeholder is “Education provided by the local community”, which can be connected to the subcategory “Impact on schooling outcomes”. Similarly, the subcategory “Health issues for Children as consumers” can be expanded to examine how *Children* are affected by labor associated with the system. If this relocation had occurred before this study, the new stakeholder would have been recorded in an additional 12 % of the total number of studies. As it stands, two texts consider this stakeholder. Vinyes et al. and Martinez-Hernandez et al. reference a similar indicator, “Children’s Environmental education” and “Children Education”, respectively, both of which can be linked to the subcategory “Education provided by the Local Community” [53,66]. The subject is not discussed beyond the increase in Children’s schooling and development, particularly in relation to environmental information.

4. Conclusions and recommendations

Current research on S-LCA in biorefineries primarily focuses primarily on the analysis of foreground systems, emphasizing the evaluation of stakeholders such as *Workers* and *Local Community* through quantitative indicators like the average wage-to-minimum wage ratio and job creation. Challenges have been identified in assessing larger stakeholder categories, such as *Society* or *Consumers*, due to difficulties in collecting contextual information from a significant number of individuals within limited time and resources. The analysis shows a preference for quantitative indicators as they are easier to compare against socio-economic reference scales. However, it should be noted that no reference scale is universal, which presents challenges in evaluating whether a social impact constitutes a gain or a loss and complicates comparisons between studies. There is also a tendency to relegate the use of scales in its entirety, equating positive social impact with legally mandated actions, effectively reducing it to the minimum requirements for the legal operation of a biorefinery. The major limitation in various studies is that, to complete an assessment, the complexity of social issues must be simplified into measurable quantities or risk making the process onerous and intricate.

Key recommendations for the S-LCA of biorefinery systems focus on standardizing the field of study. There should be a concerted effort to define which subcategories and associated data, whether quantitative or qualitative, should be considered vital for the assessment of biorefinery development. This effort should include defining various parameters to avoid commonalities (e.g., job generation/local workforce duality) and ensure they mean the same for all practitioners within the field of study. Positive impact should not be limited to the bare minimum legal requirements, moving away from the typical business-as-usual model. Additionally, stakeholders should be included in the assessment prior to implementation, even if through social acceptance surveys, to identify potential social hotspots before they evolve into negative impacts. If developing a one-size-fits-all methodology is not feasible due to system dissimilarities, addressing the requirements for a valid methodology should be prioritized. By addressing these gaps, future LCA research can provide a more balanced and comprehensive evaluation of biorefinery sustainability, supporting the development of more socially responsible practices.

Ultimately, biorefineries do not operate in isolation; they are part of a complex socio-economic and environmental landscape. Therefore, a comprehensive understanding of their social implications is essential to ensuring their long-term success and fostering a truly sustainable bioeconomy. Collaborative efforts in refining S-LCA methodologies and promoting stakeholder engagement will be vital to realizing the full potential of biorefineries in contributing to a sustainable future.

CRediT authorship contribution statement

Joana Ortigueira: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tiago F. Lopes:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Data availability

Data will be made available on request.

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