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Progress of social assessment in the framework of bioeconomy under a life cycle perspective

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ABSTRACT

The bioeconomy is positioned as a sustainable pathway to address the climate crisis and decrease the consumption of fossil resources. Life cycle methodologies are recognised as useful tools for assessing sustainability issues of production and consumption patterns. Nevertheless, the Social Life Cycle Assessment (S-LCA) methodology is less explored despite its potential, although it is true that social sustainability assessment in promoting bioeconomy strategies requires more attention. This study describes the state of the art of the S-LCA methodology under the bioeconomy framework, critically analysing the main procedural and practical issues of its implementation, and the eventual specificities, as well as providing some of the challenges for future studies. This review highlights methodological weaknesses that require further research, related to the definition of system boundaries and cut-off criteria, the method of impact assessment, and the selection of societal issues and stakeholders, as well as uncertainty, among others. In addition, particularities of the bioeconomy in the life perspective were noted, such as multifunctionality and allocation issues of bio-based products, as well as the strong interest in biofuel production systems. Therefore, more efforts are desirable to address the diversity of challenges towards the progress of the S-LCA method in line with other life cycle approaches (environmental and economic). However, the updated S-LCA Guidelines represent a useful and valuable starting point on the way towards a comprehensive (i.e., diverse social concerns) and standardised social assessment under a life cycle perspective.

1. Introduction

In the last two decades, bioeconomy has been proposed as a key strategy to promote sustainable development [1]. The definition of bioeconomy could primarily be known as the application of biotechnology in production processes based on renewable resources consumption [2]. Nevertheless, bioeconomy can be considered a wider concept because of the different perspectives that motivate its origin. In this regard, Bugge et al. [3] established biotechnology, bio-resource, and bio-ecology, as the three visions of this concept. The first one highlighted the relevance of research, application, and commercialisation of biotechnology; the second one focused on the upgrade and the biological raw materials conversion; the last one referred to the relevance of ecological processes and biodiversity promotion. Nevertheless, they converge on the aims of reducing bio-resource waste and developing new value chains and value-added products.

The strong interest in this framework inspires the design and implementation of various national and international strategies and policies [4]. Indeed, according to the Organisation for Economic Co-operation and Development (OECD), around 50 countries have a national strategy or policies consistent with a bioeconomy framework [5]. However, a shift towards a bioeconomy is not sustainable per se [6], and its performance must be assessed from a holistic and quantitative perspective, involving not only the economic and environmental dimensions but also the social one. In this sense, Bugge et al. [3] identified that natural and engineering sciences dominate the studies about bioeconomy, and the social perspective has been less explored. Similarly, Sanz-Hernández et al. [1] highlighted the need for a deeper analysis of social implications in this field, concluding that empirical research and the development of refined methodologies are still required.

The supply chains and processes implied in the bioeconomy are multiple and diverse, from the cultivation of feedstocks to the final disposal of the product or its valorisation process. Hence, understanding the cumulative impacts contributed by each sector along the supply chain is relevant for the sustainability performance of the product. Life-cycle-based methodologies are well-established and useful tools for the assessment of sustainable production patterns [7]. They focus on the

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Abbreviations definition

S-LCA	Social Life Cycle Assessment
E-LCA	Environmental Life Cycle Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
ISO	International Organisation for Standardisation
FU	Functional Unit
sLCIA	Social Life Impact Assessment
PRP	Performance Reference Point
OECD	Economic Co-operation and Development
SO-LCA	Organisational Social Life Cycle Assessment
SHDB	Social Hotspot Database
GTAP	Global Trade Analysis Project
SHIs	Social Hotspot Indexes
PSILCA	Product Social Impact Life Cycle Assessment
PRISMA	Preferred Reporting Items of Systematic reviews and Meta-Analyses
WoS	Web of Science
HDI	Human Development Index
W-HDI	Workers' Human Development Index
AHP	Analytic Hierarchy Process
SDG	Sustainable Development Goals
UNEP	United Nations Environment Programme
PCR	Product Category Rule
MCDA	Multicriteria Decision Analysis

three pillars of the sustainability concept: *i*) environmental: Life Cycle Assessment (LCA or E-LCA); *ii*) economic: Life Cycle Costing (LCC), and *iii*) social: Social Life Cycle Assessment (S-LCA). These methodologies assess potential impacts related to each sustainability dimension throughout products or/and service life-cycle (i.e., from raw materials extraction to the end-of-life stage). In a step forward, their integration lies in a Life Cycle Sustainability Assessment (LCSA) for adopting a sustainable perspective and highlighting trade-offs among them [8]. Traditionally, the sustainability assessment through a life-cycle perspective has been mainly focused on the environmental and economic dimensions, leaving behind attention on the social pillar. Consequently, lower maturity progress referred to methodological aspects of how social impacts should be evaluated through a life-cycle approach is observed [8,9]. However, current interest in the S-LCA methodology attracts the attention of the scientific community. In 2009, the first Guidelines for Social Life Cycle Assessment of Products (hereafter Guidelines) were published [10], setting the initial pathway for its standardisation and robustness, as well as motivating the first studies that applied this methodology. Recently, Ferreira et al. [11] highlighted a common employ of S-LCA to quantify the potential social implications of bioeconomy.

The guidelines understand social impacts as consequences of social interactions in the context of one activity (production, consumption, or disposal) and/or caused by it and/or by the prevention or reinforcement of actions carried out by stakeholders (e.g., the implementation of safety measures in a facility) [10]. Thus, this document defines the S-LCA methodology as an impact assessment tool that evaluates the social and socio-economic aspects (positive and/or negative) of products throughout their life cycle. Thus, its methodological framework follows, with some particularities, the four-step procedure of the ISO framework [12,13]. In 2020, an updated version entitled "Guidelines for Social Life Cycle Assessment of products and organisations" [14] (hereafter Updated Guidelines) was launched to define a new frame of reference due to the absence of consensus on S-LCA.

The aim of this study is to outline the current progress of S-LCA in the bioeconomy framework, identifying the main methodological developments and the possible adaptation of the tool in bio-based systems (biorefineries, bioenergy, and bio-based products). Accordingly, the research questions addressed are: i) What is the trend in the S-LCA approach applied in the bioeconomy framework? ii) What is the methodological progress of S-LCA in assessing bio-based systems? iii) How has the S-LCA method been applied in the bioeconomy? iv) Which bio-based systems have been the most studied? v) What are the main methodological aspects that require attention in future applications of S-LCA? In this way, this study presents the state of the art of how social assessment has been addressed under a life-cycle perspective, identifying difficulties of its implementation and potential research lines in the bioeconomy framework.

This manuscript is structured as follows: Section 2 presents a brief theoretical background of S-LCA. Then, Section 3 shows the search procedure of the state of the art, and Section 4 presents the bibliometric analysis of the sample. After that, Section 5 describes the progress of the S-LCA methodology based on the topics addressed. Section 6 explains the methodological issues identified for each step of this tool. Finally, Section 7 presents the main weaknesses in its application and suggests some issues to address, and Section 8 shows the conclusions of this research.

2. Brief theoretical framework of S-LCA

Guidelines describe how social and socio-economic impact assessment would be performed through a life cycle perspective. It proposes a twofold classification of social impacts: by stakeholder and by impact categories. According to the Guidelines [10], E-LCA and S-LCA have similar characteristics. Some of them are: *i*) They require an exhaustive data collection process; *ii*) Their purpose is to estimate the life cycle impacts attributed to the product/service; *iii*) They are iterative procedures; *iv*) They encourage peer review when planning communication or comparative statements; *v*) They are a useful framework for decision-making.

The Guidelines were complemented by the Methodological Sheets for Social Life Cycle Assessment in 2013 [15]. These methodological sheets presented and defined impact subcategories, proposed generic and specific indicators, and provided database sources for collecting them. In addition, the great interest in social performance motivated the launch of the Handbook for Product Social Impact Assessment in 2016 by the Roundtable of Product Social Metrics [16,17]. Some key aspects of conducting an S-LCA study are presented as follows.

2.1. Goal and scope definition

This stage establishes the objective and scope of the product system under study, which will determine its methodological framework (stakeholders, allocation procedures, impact methods, etc.) [14]. As in E-LCA, both Guidelines recommend the definition of the functional unit (FU), since it defines quantitatively the study purpose.

2.2. Life cycle inventory

Here, it is identified and collected all flows of the product system, and then normalised by the selected functional unit. In addition, the activity variable (e.g., working hours) should be also obtained where appropriate. This variable allows for determining the contribution of each stage/company all over the life cycle of the product.

2.3. Stakeholders and impact assessment methods

In the product value chain, processes can be related to geographical locations. In these geographical locations, socio-economic and social implications can be grouped based on five stakeholders' dimensions: local community; workers; society (national and global); consumers; and value-chain actors. Based on selected stakeholders, both inventory data and impact method must be specified. Furthermore, the participation of stakeholders is also highlighted in the evaluation [10].

Both positive and negative impacts can be determined in the social analysis. The social impact assessment (sLCIA) phase comprises the three steps of the ISO 14044 framework [10]: Impact categories selection and characterisation methods and models; Association inventory data to sLCIA subcategories (classification); and determination of subcategory indicator results (characterisation). Moreover, the sLCIA encompasses two methods [14]: *i)* The Reference Scale Approach (Type I), which uses specific reference points of an expected activity (called performance benchmarks - PRPs); and ii) The Impact Pathway Approach (Type II), which considers a causal relationship between the organisation product system/activities and the resulting potential impacts. Thus, for determining the potential social impacts of a product/service system, practitioners should use Type I, while whether it is to predict their consequences, they should utilise Type II.

2.4. Interpretation phase

This stage requires analysing and communicating the results adequately, explaining the potential limitations, providing recommendations, and drawing conclusions. The requirements of ISO 14044 [13] such as completeness, consistency, sensitivity, and quality of data, should be followed.

2.5. UNEP guidelines S-LCA 2020

This version presents an organisational approach to the social LCA methodology (SO-LCA). In addition, a new stakeholder category "Children" and sub-categories have been introduced (see Fig. 1). Furthermore, the principle of materiality is proposed, which consists of determining the proportion of social performances/impacts allocated to life cycle phases, processes, and/or stakeholders.

The Updated Guidelines establish that when a social life-cycle study is conducted, the procedure that should be followed is (see Fig. 2): *i)* Goal and scope definition, determining a product or organisation assessment; *ii)* Select the impact assessment method, stakeholders, and social themes; *iii)* Perform the inventory analysis, deciding whether to collect data from generic or site-specific data; *iv)* Apply the impact method(s); *v)* Interpret and communicate the results.

2.6. S-LCA databases

2.6.1. Social hotspot database (SHDB)

SHDB is the first commercial S-LCA database that encompasses generic social data to attribute social risks to country-specific sectors associated with the assessed product [18]. Moreover, it is composed of three main components: the Social Theme Tables, a Global Input-Output model derived from the Global Trade Analysis Project (GTAP), and a working hour model [19]. The social themes are organised into five categories (see Fig. 3), and it contains more than 157 risk indicators grouped into 30 topics, as well as information related to 244 countries and 57 economic sectors [20].

Within SHDB, the impacts are quantified based on "risk hours", which represents the weighted cumulative labour hours throughout the life-cycle, where workers may be at risk for a specific social issue [21]. The characterisation model assesses social impacts in four levels of risk: low, medium, high, or very high risk. Therefore, the indicators attribute social risk to social issues within the impact category [18]. For instance, the indicator of the percentage of work >48 h per week in the country can be employed to assign risk for the theme of excessive working time in the "Labour Rights and Decent Work" impact category. Weighting factors are then used to designate the relative likelihood of an adverse situation occurring [22]. The resulting weighted risks for each social impact category, expressed in terms of average risk equivalent hours, are aggregated into social hotspot indexes (SHIs) using a weighted sum approach [18].

2.6.2. Product social impact life cycle assessment (PSILCA) database

PSILCA, developed by GreenDelta® [23], is a database compatible with well-known software for E-LCA methodology such as OpenLCA® and SimaPro®. PSILCA adopts a multi-regional input-output database, which includes data from almost 15,000 sectors for 189 countries [23]. Social impacts are estimated for each category, by aggregating social risks of all processes within the boundary under study. Social risks are scaled by price, labour hours, and characterisation factors. This database encompasses the impact method "Social Impact Weighting Method" which explains the exponential relationships among impact factors [23].

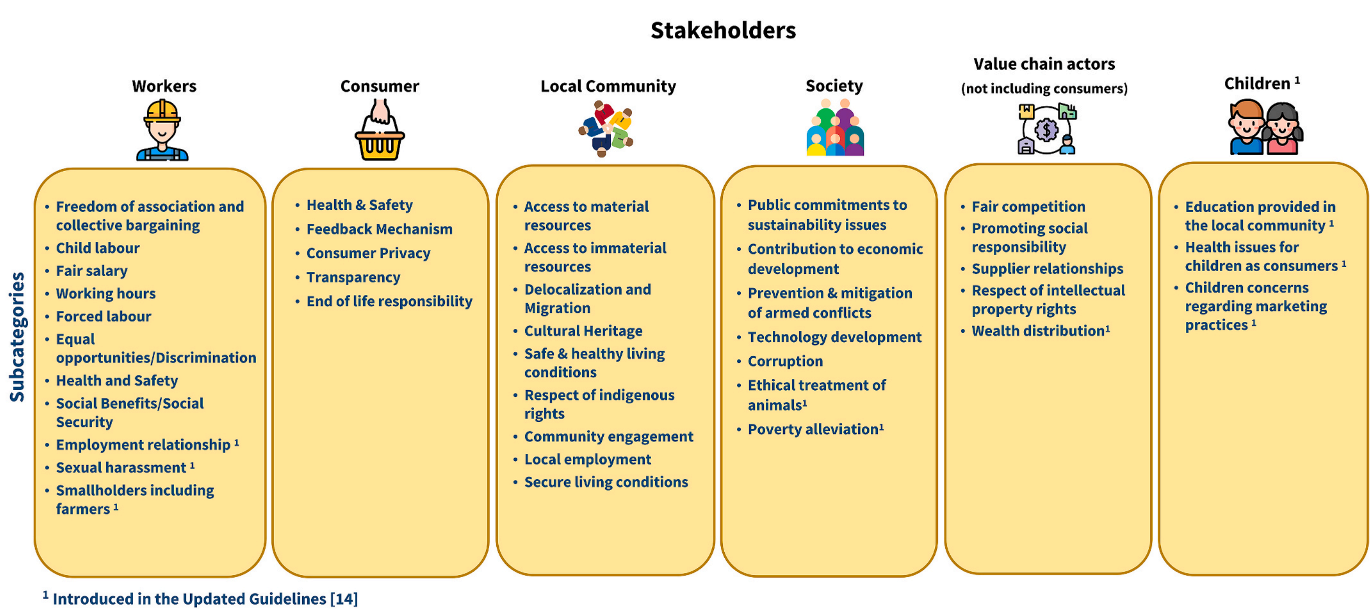

Fig. 1. Stakeholders and subcategories based on Updated Guidelines [14].

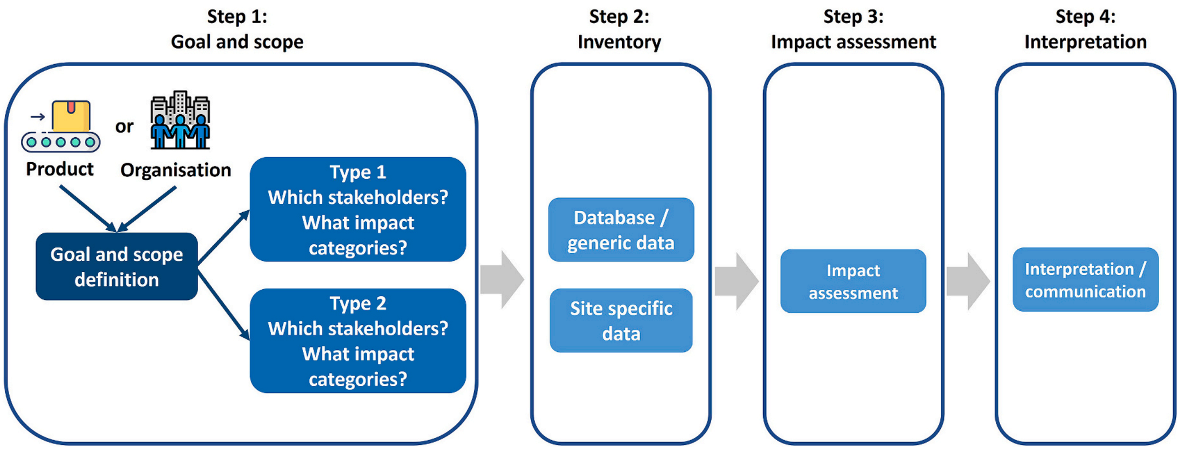

Fig. 2. Schematic procedure of S-LCA based on the Updated Guidelines [14].

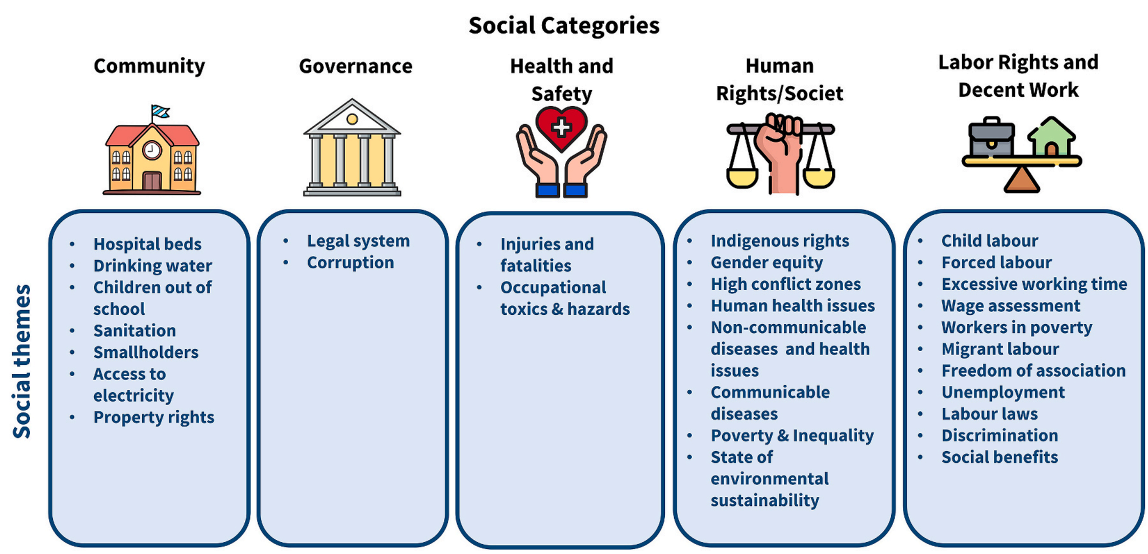

Fig. 3. Social impact categories and topics in SHDB.

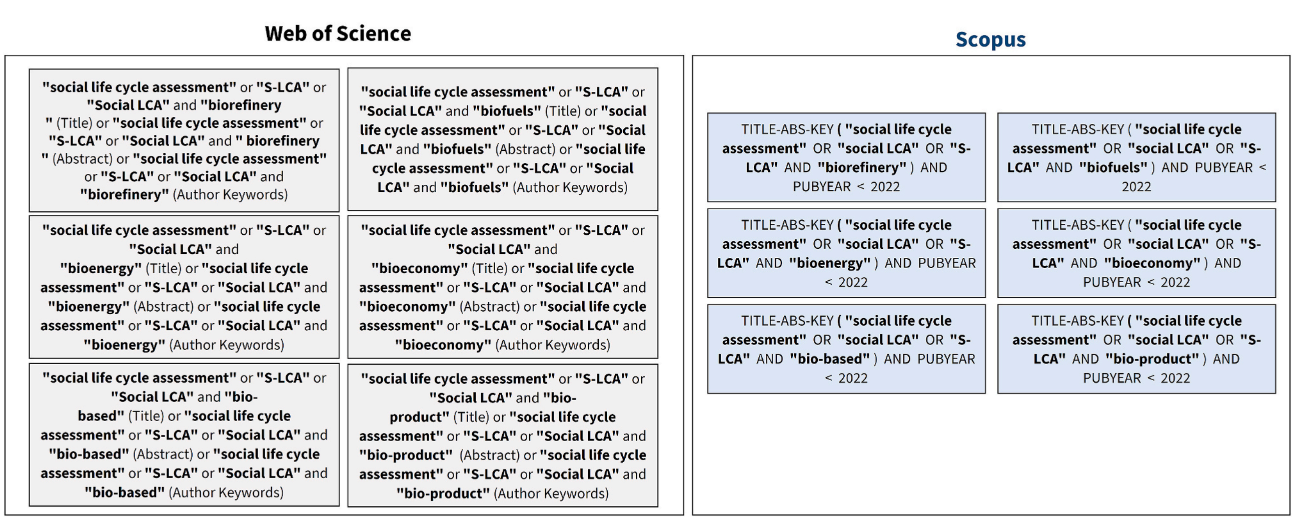

Fig. 4. The keywords used for search in databases.

3. Research methodology

3.1. Search procedure

The methodological procedure for searching and selecting the sample of articles was performed based on the Preferred Reporting Items of Systematic reviews and Meta-Analyses (PRISMA) method [24]. The procedure is described as follows:

i. Studies identification and database search: A search was conducted in the Web of Science (WoS) and Scopus databases in March 2022, using the sets of keywords presented in Fig. 4. The selected publications were those published before 2022 (i.e., until 2021 included).
ii. Article management: All manuscripts were handled through the Mendeley® software, where all articles duplicated were removed.
iii. Screening title, abstract, and keywords: All the titles, abstracts, and keywords of each article were read to determine their suitability for the research topic of this state of the art. Thus, those articles published in a language other than English were removed, as well as those not related to bioeconomy systems (e.g., bioenergy, biofuels, bioproducts, biorefineries) and no access (conference papers).
iv. Full-text reading (eligibility): After identifying and selecting articles, the full texts were read. The decision to retain or exclude articles after a full reading was based on whether they used the life cycle approach in the social assessment of bioeconomy, following both available Guidelines.
v. Analysis of the research profile: a descriptive analysis is conducted for the sample of selected articles.

Following this procedure, a total of 55 articles were obtained, including original research, conference papers, and book chapters. Fig. 5 presents the results related to the number of articles obtained in each step of the search procedure. The exclusion of non-English articles and the grey studies that could introduce forthcoming research may represent some limitations in this study. In addition, the sample analysis was carried out by two authors independently, and the evaluation performed was jointly verified to check potential disagreements.

The selected sample was analysed according to the main methodological features of the S-LCA tool to identify difficulties in its development. Accordingly, the topics addressed are presented as follows:

i. Bibliographic information: Authors, year, title, source.
ii. Purpose of the study: Theoretical (methodological aspects or review studies), methodology application or both.
iii. Methodology applied: S-LCA alone or combined with LCC or E-LCA or corresponds to LCSA.
iv. The bio-based system or product evaluated.
v. Stakeholders: Class of stakeholder considered.
vi. Social themes: Social themes or subcategories considered.
vii. Impact assessment: The use of the Reference Scale Approach (Type I) or the Impact Pathway Approach (Type II).
viii. Definition of FU and activity variable.
ix. Consideration of multifunctionality and definition of allocation method.
x. System boundary definition: Cradle to gate, cradle to market, cradle to consumer, cradle to grave, gate to gate.
xi. Definition of cut-off criteria.
xii. S-LCA database used.

These topics were selected as they represent the fundamental methodological aspects that are required to be defined when the S-LCA tool is applied, as it was briefly presented in Section 2.

4. Bibliometric analysis

To perform the bibliometric analysis of the sample, Microsoft Excel® software was used to collect the information provided by each article about the list of topics of interest. Of the total number of articles (55), different types of articles were identified: 40 were original research, seven were review studies, five were book chapters and three were conference papers (see Fig. 6). The theorical progress of the S-LCA method was the main interest in the sample, 15 articles focused on the theoretical aspects (6) and the state of the art (9), 19 proposed and applied a new framework, meanwhile 21 papers were application studies. In terms of the methodology application (40 papers), about of 58% of articles focused only on S-LCA (23 of them). Furthermore, its combination with E-LCA (seven articles) and it uses within the LCSA framework (10 papers) were identified. Regarding publication sources, considering the 47 articles (85%) published in scientific journals, the International Journal of Life Cycle Assessment has the highest number of articles (23%), but followed very closely by the Journal of Cleaner Production (21%). Sustainability journal is another popular source of these publications (14%). These results can be expected since as a life-cycle methodology, the proposed theoretical advances will be attractive in journals related to this tool. Fig. 7 presents all the scientific journals identified in this review.

First articles related to social life cycle assessment in bioeconomy appear in 2013 (see Fig. 8), and the quantity of publications was low and relatively constant until 2017. Then, an upward break is observed in 2018 with 15 articles published, and the following years the range value

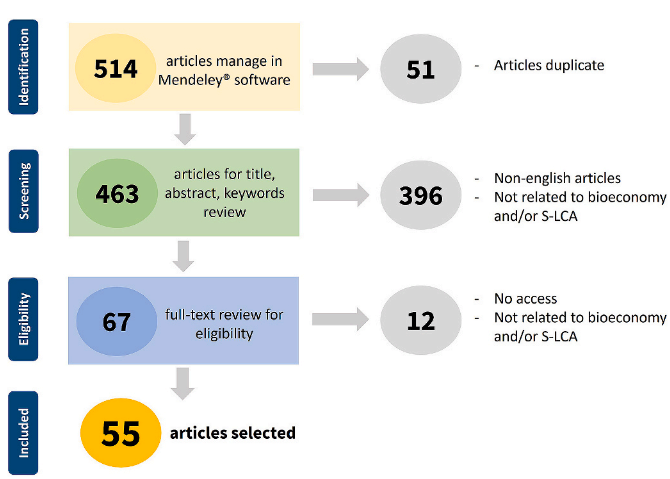

Fig. 5. Summary of the procedure performed to obtain the article sample.

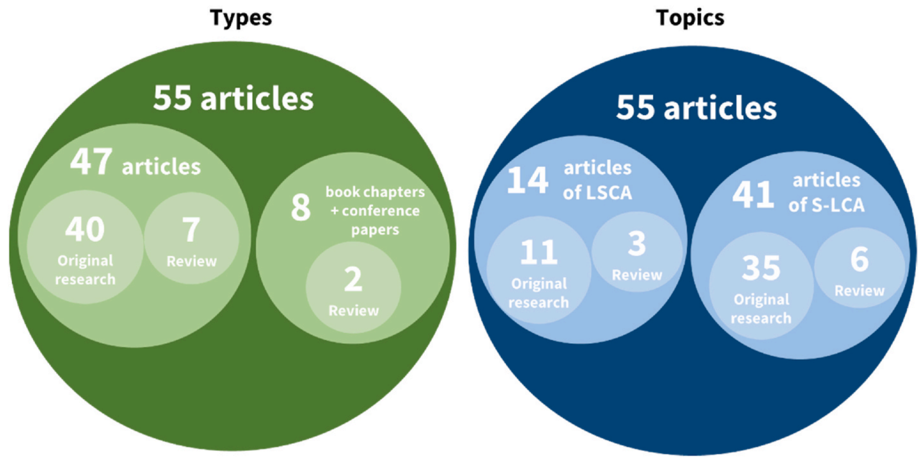

Fig. 6. Types and topics of the articles from the sample.

was from 7 to 12 articles. In the bioeconomy framework, the application of the S-LCA tool is an emerging methodology that has not yet exploited its potential, but with increasing attention lately.

To identify the progress of the methodology from a geographical perspective, the affiliation of the first author was used. The results showed a large contribution from Europe with about 60% of the total number of published articles (see Fig. 9). The leading country in this area is Germany with 13% of the total number of papers, followed by Italy with 11% and the UK with 9%. These results could reflect the key role that Europe is performing in the promotion of bioeconomy as a new economic model, and how far away other regions, such as South America or Africa, are in the development of this framework.

Bioeconomy encompasses different target systems mainly related to bioenergy generation and bioproducts (e.g., biochemicals). In this sense, the first one received the great attention in the sample. The biofuel production was the most evaluated with about 47% of the total (see Table 1). Within this system, biodiesel production as well as the production of (first and second) bioethanol from multiple feedstocks (such as sugar cane, wheat, corn, cassava, and molasses), were identified. Electricity generation is another topic of great interest with 19% of the

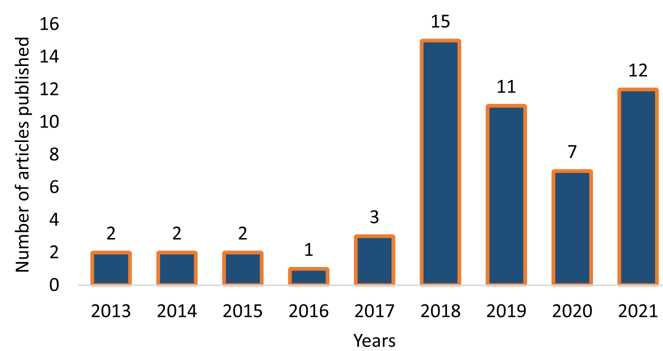

Fig. 8. Articles published per year about S-LCA and bioeconomy.

sample. Some sources evaluated for electricity production were bagasse and biomass cogeneration as well as municipal organic solid waste. In addition, conversion technologies, biomass boilers, biogas and biorefinery plants were also identified. Less attention to wastewater recovery systems for resource recovery, as well as to bioproducts such as

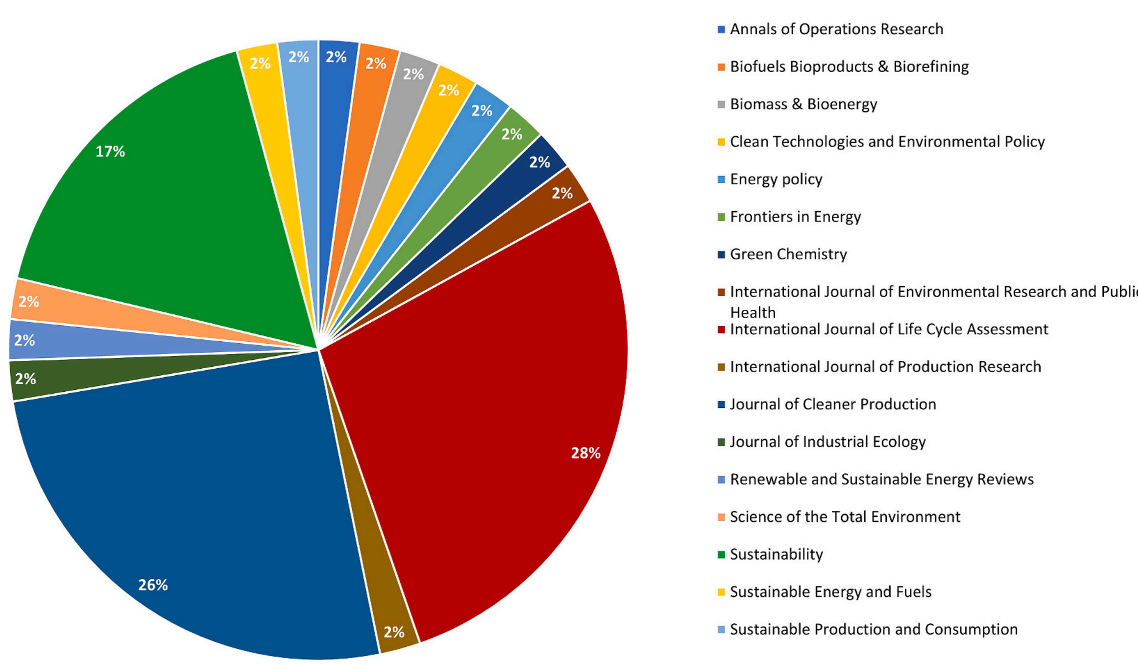

Fig. 7. Distribution of articles published per journal.

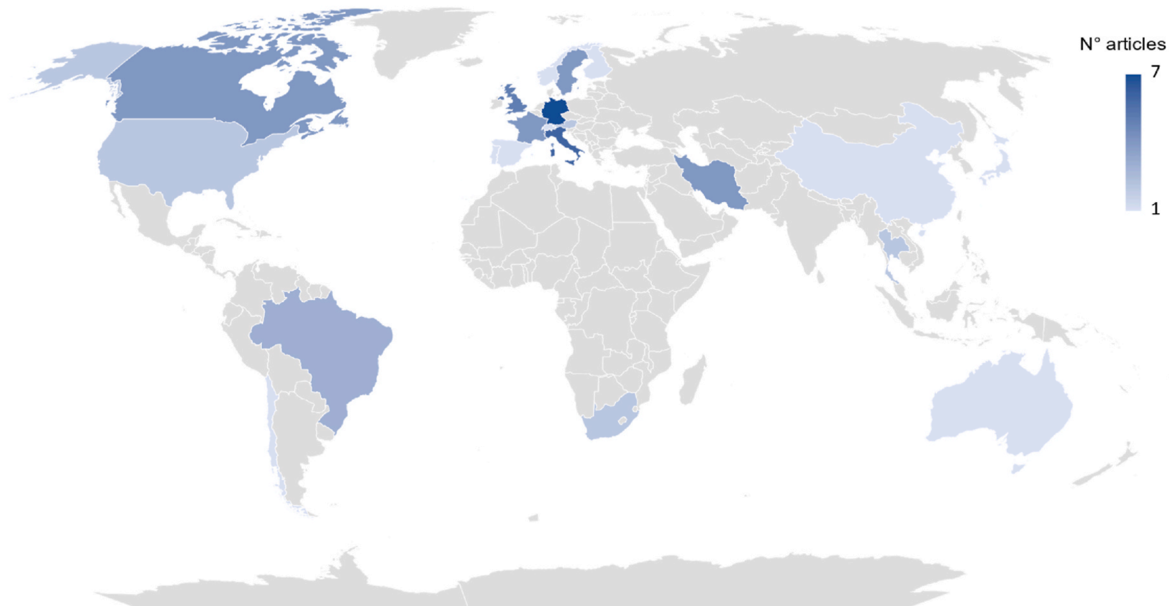

Fig. 9. Affiliation (country) of the first author.

biochemicals and bio-based packaging were observed. Thus, the generation of energy through renewable sources dominates the social concerns in the promotion of the bioeconomy, due to its relevant role in the achievement of a low-carbon economy. Nevertheless, bioeconomy is a wider concept, and emphasis should move to other biomass use, e.g., bioplastics, as they have been supported by public institutions for their production and use.

Table 1
Case studies evaluated in the sample reviewed.

Case study	N° Articles	References
Biorefinery	3	Cadena et al. [28], Sadhukhan et al. [30], Tavakoli and Barkdoll [29],
Bio-based products	3	Falcone and Imbert [31], Imbert and Falcone [32], Ladu and Morone [33]
Bioenergy	3	Weldegiorgis and Franks [34], Guarino et al. [35], Zhang et al. [36].
Bioethanol and biochemical	1	Valente et al. [37]
Biofuels	18	Manik et al. [38], Ekener-Petersen et al. [39], Chingono and Mbohwa [40], Ren et al. [41], Do Carmo et al. [42], Do Carmo et al. [43], Do Carmo et al. [44], Souza et al. [45], Kaltenegger [46], Sajid and Lynch [47], Ekener et al. [48], Ekener et al. [49], Ghaderi et al. [50], Sawaengsak et al. [51], Macombe [52], Masilela and Pradhan [53], Souza et al. [54], Subramanian [55]
Biofuel and electricity	1	Prasara-A et al. [56]
Biofuel and animal fodder	1	Portner et al. [57]
Electricity generation	9	Contreras-Lisperguer et al. [58], Takeda et al. [21], Stamford [59], Martín-Gamboa et al. [60], Fattahi [61], Alidoosti et al. [62], Fattahi et al. [63], Nubi et al. [64], Sadhukhan et al. [65]
Forest biomass supply chain	1	Mattila et al. [27]
Wastewater-based resource recovery technology	2	Shemfe et al. [18], Foglia et al. [66]
Wood-based product	3	Siebert et al. [25], Bezama et al. [26], Siebert et al. [67]

5. Progress of S-LCA in bioeconomy

5.1. Methodological proposals for addressing the S-LCA approach

As expected, most of the studies under review reported following the Guidelines to apply and develop different methodological frameworks for S-LCA. In a geographical assessment approach, Siebert et al. [25] developed a regional S-LCA framework (called "RESPONSA") to address regional social impacts, using the Type I impact method, in places where most production activities can be identified. According to these authors, to analyse regional social effects from a life-cycle perspective, the assessment of regional processes in the foreground is required, as well as possible social effects outside the regional system boundaries. Then, Bezama et al. [26], applied this framework coupled with E-LCA for assessing wood value chains. Furthermore, Mattila et al. [27] compared the prioritisation of global and local approaches to social assessment and explored their integration into a single indicator score, through a multi-criteria perspective.

The evaluation of bio-based systems at early design stage is relevant to guarantee proper sustainable conditions when the process could be implemented. Accordingly, Cadena et al. [28] proposed a quantitative methodology to measure social effects of a production process design. Their framework estimates the potential benefits and risks of an operation system, for example, a biorefinery. The proposed methodology starts with defining the objective and scope, collecting data on all stakeholder-related activities. This is followed by identifying and ranking (according to priorities) the stakeholders affected. After that, the most relevant social metrics are selected. For this, a combined approach of the Type I and II impact methods are suggested.

In a production perspective, Tavakoli and Barkdoll [29] developed a framework entitled "Blended Lifecycle Integrated Social System" (BLISS) that illustrates the relation among production lines, relevant indicators and stakeholders concerned. In addition, the sLCIA step determines how each stage of production affects the final product. Then, standard values are defined for each indicator related to each production step, and inventory values are scored, which could be assigned to each stakeholder.

Other studies assess social performance of bio-based products through financial models. Imbert and Falcone [32] proposed a framework through a two-step analysis: i) identify and mapping of relevant stakeholders in accordance with their influence and interest in bio-based products; ii) validation and integration of relevant categories, subcategories and social indicators, through the opinion of the identified stakeholders. Meanwhile, Sajid and Lynch [47] developed a method to quantify the social implications of products through the monetary value perception of these impacts.

5.2. Improvements in methodological stages of S-LCA

Both Guidelines represent the theoretical foundation for the development of further methodological concerns in this tool. The methodological aspects proposed are presented based on the life-cycle stage that they addressed.

5.2.1. Goal definition and life cycle inventory stages

The scope definition and the identification of the multiple actors in the supply chain are fundamental for assessing social impacts in a life-cycle perspective. Thus, Martín-Gamboa et al. [60] proposed a protocol that combine the use of trade and inventory databases to identify supply chain pathways within the product boundaries. First, in the scope definition phase, the supply chain of the product is determined, identifying the origin of processes involved (i.e., countries), and then establishing its boundary. After that, the inventory stage is performed by collecting the social data of all processes that belong to that boundary. Furthermore, in the inventory stage, Souza et al. [68] presented a hybrid model integrating S-LCA and input-output analysis to quantitatively determine social effects on sugarcane biorefinery supply chains with vertically integrated production systems and focusing on Workers stakeholder.

5.2.2. Impact assessment stage

The linear assumption for translating qualitative into a quantitative results was addressed by Do Carmo et al. [43], developing specific value functions for each subcategory, and establishing weighting factors for the indicators used in each stakeholder. In addition, in the Type I sLCIA method, Do Carmo et al. [44] proposed a four-step method to handle the uncertainty of scoring and weighting factors of the experts' value judgment. Meanwhile, Sawaengsak et al. [51] presented a weighted aggregation method to evaluate social categories and sub-categories, using a cause-effect chain analysis to identify all possible sources of social problems.

A new characterisation model is proposed by Souza et al. [54] to assess the human development of workers called "Workers' Human Development Index (W-HDI)", inspired by the Human Development Index (HDI). Therefore, this impact indicator covers aspects of health, income, and education of workers in different economic sectors related to a production chain. To apply this method, the social metrics used were the number of jobs, occupational accidents, and educational and wage profiles. Furthermore, Falcone and Imbert [31] highlighted the role of consumers in the market adoption of bio-based products, by identifying and proposing the main categories and impact indicators for the evaluation. These authors highlight the importance of the effective inclusion of some social indicators to make informed and conscious purchasing decisions, such as *i*) end users' health and safety, *ii*) feedback mechanisms, *iii*) transparency, and *iv*) end-of-life responsibility. The categories proposed were Health and Safety, Social Acceptability, Human Rights and Working Conditions, Food Security, Employment, Income, Access to Material Resources, Gender Issues and Discrimination, and Land Use Change.

For positive social implications, Ekener et al. [49] included them as the fulfillment of positive rather than as a lack of negative impacts. Indicators were categorised in four different levels following the SHDB impact method. According to these authors, subcategories with positive social impacts are *i*) Workers: local employment, *ii*) Local community: Economic development, Infrastructure development; *iii*) Society: Technological development, among others.

Finally, some studies focused on specific sectors to adapt the S-LCA methodology. Thus, Siebert et al. [67] established a set of indicators to assess social effects of wood-based products. Moreover, Alidoosti et al. [62] adapted the stakeholder subgroups and indicators for evaluating bioenergy supply chains based on municipal solid waste. Accordingly, subcategories such as "bioenergy quality", and indicators such as "impact on decreasing non-renewable energy imports", "the content of energy produced per unit of bioenergy generated", "reduction rate of greenhouse gas compared to the previous situation", among others, were proposed.

5.3. Social assessment in the LCSA methodology

New strategies were proposed to apply the LCSA perspective, for example, when an energy system is evaluated, Guarino et al. [35] introduced two additional stages in this methodology: *i*) Constructal law for the energy design and *ii*) the life-cycle exergy analysis. The concept of capitals in this methodology is addressed by Subramanian et al. [55], examining the stocks and flows of eight types of capital (human, natural, manufactured, social, digital, political, cultural, and financial) in an industrial symbiosis context. In a regional bioeconomy approach, Zeug et al. [69] linked indicators and impact methods for a sustainability framework (societal needs, provisioning system, planetary boundaries). Finally, Sadhukhan et al. [65] presented a web-based open-source software product to support the design process using LCSA methodology. Concerning the S-LCA approach, the SHI score was considered.

5.4. Coupling S-LCA with other methodologies

Combining LCA and non-LCA metrics (circularity aspects) to support sustainability report process of bio-based products was addressed by Ladu and Morone [33] through a four-step framework: *i*) areas of protection identification; *ii*) principles and indicators definition for each area; *iii*) operationalising the tool (i.e., scoring system); and iv) case study application. In their case study, the selected areas of protection were indirect land use change, circularity, as well as sustainability dimensions. Furthermore, Sadhukhan et al. [30] applied techno-economic, E-LCA and S-LCA analysis, for evaluating the sustainability performance of macroalgal biorefinery systems to obtain different chemicals.

5.4.1. Multi-objective optimisation

Multi-objective optimisation (also known as multicriteria or Pareto optimisation) is a multiple-criteria decision-making approach, related to mathematical optimisation problems that seek to enhance simultaneously various objective functions. Coupling optimisation models with life-cycle methodologies is an useful approach in the sustainable assessment [70,71], particularly when the design of a bio-based supply chain or a biorefinery platform present some trade-off issues. In this regards, Ghaderi et al. [50] proposed a multi-objective programming model that sought to maximise the average value of switchgrass-based bioethanol supply chain performance by quantifying environmental and social impacts. The social function seeks to maximise the social responsibility of the supply chain, considering the balance between employment and economic development. Fattahi [61] proposed a dual-objective stochastic model to design a recovery network of municipal solid waste (plastic, paper and organic waste) for energy generation under a social responsibility. Thus, the model balances economic costs and social responsibility of technologies such as: *i*) landfilling with gas recovery system, *ii*) incineration, *iii*) anaerobic digestion, and *iv*) advanced thermal treatment with pyrolysis and/or gasification. Considering both environmental and social impacts, Fattahi et al. [63] proposed a stochastic model to design and plane a biomass value chain for energy generation, taking into account seasonality and uncertainty of feedstock yields (agricultural residue, forest residue, livestock manure). For the social perspective, the function obtains a social score of power technologies equal to or higher than a minimum acceptable rate, based on job-related indicators mainly. An interesting thing is that these studies do not use an impact method (Type I or II). Fattahi et al. [63] quantified the impacts in the optimisation model, Ghaderi et al. [50] normalised and weighted the measured impacts, and Fattahi [61] employed fuzzy analytic hierarchy process (AHP) approach to quantify social indicators based on the opinions of experts.

5.4.2. Case studies on life cycle sustainability assessment

From the total of articles reviewed, seven of them were focused on LCSA application, mainly, in bioenergy and biofuel systems. Ren et al. [41] and Ekener et al. [48] combined LCSA and the multicriteria decision analysis (MCDA) to determine sustainable biofuels production. Contreras-Lisperguer et al. [58] measured the potential impacts of the bagasse cogenerated bioelectricity comparing two power plants. Stamford [59] evaluated the sustainability of large-scale biomass-fired electricity generation. In the social approach, the author used indicators of the E-LCA methodology (human toxicity potential, depletion of abiotic resources - elements and fossil fuels), arguing that environmental issues have direct social consequences. Masilela and Pradhan [53] compared the biomethane and biohydrogen production from organic wastes such as agro-industrial, urban, and rural settings. For social qualitative inventory data, authors used the numerical verbal judgment approach (i.e., Likert-type scale) to transform them into quantitative datasets. Finally, Zhang et al. [36] assessed the energy utilisation of crop residues through a qualitative analysis.

5.5. Other reviews about the S-LCA methodology

Regarding the six S-LCA review articles identified (see Fig. 6), three studies focused on biofuels production [72–74]. Meanwhile, Julio et al. [75] reviewed E-LCA studies related to biorefineries, and proposed a framework for a sustainable design of processing routes. In this scheme, they proposed a multiobjective optimisation for the eventual conflicts among the three sustainability pillars. An overview on the sustainability assessment of bio-based plastics based on E-LCA, LCC and S-LCA methodologies was provided by Spierling et al. [76]. Furthermore, Vidaurre et al. [77] identified those relevant aspects for the social assessment of bio-based value chains in studies that used the Methodological Sheets of the Guidelines. These authors highlighted the focus on the "smallholders and family farms" stakeholder for land-based systems (i.e., agriculture and forestry), although it is not present in the first Guidelines. Then, smallholders were introduced as impact subcategories in the updated version, see Fig. 1.

6. Main findings in the methodological analysis

6.1. Identified aspects related to goal definition stage

Social assessment is often based on qualitative information, which makes it complicated to express results based on the unit of system output. Although both Guidelines and Updated Guidelines recommend the definition of the FU, this is not commonly addressed in most of the manuscripts selected. Difficulties related to how connect qualitative data to a reference unit could be one of the main reasons, especially, when reference set points method is used (i.e., Type I). Otherwise, Guidelines indicate that the FU cannot be considered when social impacts are related to an organisation behaviour instead of motivated by the activities required to elaborate a product. Thus, the proper definition of the approach followed (product or organisation) is essential for this topic. Of the 40 articles containing case studies, 23 of them declared the FU applied (i.e., about 58%), but considering the manuscripts that only applied the S-LCA method (23 articles), only 11 of them reported which FU was used. For example, Cadena et al. [28] considered the biorefinery capacity as FU; meanwhile, Nubi et al. [64] defined it as the waste management for electrical power generation. When S-LCA merged with E-LCA (seven), four articles declared the FU. For example, Portner et al. [57] stablished a social inventory in terms of working hours per FU, and Prasara-A et al. [56] associated inventory indicators to 1 kt of sugarcane. Regarding the LCSA studies (11), eight presented explicitly the FU selected mainly when the E-LCA dimension was presented, and no connection with S-LCA was referred to. Since these tools follow the same four-step ISO framework, it could be recommended to refer to these methodological aspects (i.e., FU, cut-off criteria, boundaries, etc) as the assumptions followed for all perspectives.

Regarding activity variables, only seven articles reported their use, three studies [42–44] included the quantity of workers involved in each life cycle stage, and Martín-Gamboa et al. [60] used working hours to quantify the activities of each process within a bioelectricity system. In the new frameworks proposed, Sajid and Lynch [47] defined it as impact categories and subcategories in their "GreenZee" model, Siebert et al. [25] consider activity variables to attribute the proportion of social outcomes of individual organisations to the final product, and Zeug et al. [69] stated that FU is not enough to account for impacts, and activity variables need to be used. Thus, they categorised indicators by a FU (material flow) or an activity variable (working hours).

The purpose of bio-based systems (e.g., biorefineries) includes the production multiple products or services (e.g., feed, chemicals, materials, and bioenergy). Thus, the concept of multifunctionality plays a relevant role in the social assessment of products. However, this issue was not pursued in any of the articles from the evaluated sample. In this sense, only Souza et al. [78] stated to interpret their results as a global effect, avoiding assigning social effects to a single product. Although allocation is not always needed, due to the scope of social data (e.g., organisation issues), when a product analysis is performed, the ISO 14040–14044 should be followed. Thus, activity variables can be useful to address allocation/partitioning issues.

Regarding boundaries definition, about 72% of the studies stated the scope followed. It was common to observe that studies mentioned individually all stages involved rather than using the life-cycle terms (e.g., cradle to gate). From the 40 application studies, about 38% followed a cradle to gate perspective, 13% from cradle to market (i.e., demand centres), 13% from cradle to grave, 8% from cradle to consumer, and 3% (one paper) from raw material extraction to seaport. Furthermore, only Takeda et al. [21] and Martín-Gamboa et al. [60] referred to a cut-off criteria for data collection process, and flows exclusion in the definition of supply chains, respectively.

6.2. Identified aspects in the life cycle inventory stage

For inventory performance, the most common ways of collecting data were through activities such as focus groups, symposia, or workshops. Mainly, a group of experts (academic institutions, government agencies, industry leaders, NGOs and community leaders) presents their opinion related to the assessed system and identifies the main affected stakeholders, as developed in some reports [38,39,41]. In addition, data were also collected through interviews and questionnaires, national statistics, international trade flows, scientific articles, and databases (e.g., SHDB). Through expert panels, different studies identified relevant social subcategories and indicators were identified and assessed through a judgement scoring process (e.g., using a Likert-type scale). Regarding databases used, of the articles that used the S-LCA (42), 13 of them used the SHDB and only two used the PSILCA database. The low use of databases could be related to their recently launched, but they can be helpful, when they reach compatibility with other life cycle software, especially, with those related to E-LCA.

6.3. Identified aspects related to impact assessment, stakeholders, and social themes

Regarding the impact methods, from the 40 articles that applied S-LCA (alone, with E-LCA, or within LSCA), 13 studies used the Type I method: six of them reported the use of PRP approach and seven used scoring systems (e.g., Likert scale). In addition, 10 articles did not report the use of an impact method and only mentioned the indicators evaluated. Eight articles reported that followed the SHI score (through SHDB), and two articles used PSILCA characterisation factors [57,60]. Moreover, two studies performed a qualitative analysis of the impact indicators [36,58]. Only one article followed the Type II approach to assess social consequences [78]. Otherwise, four articles proposed new approaches: Sajid and Lynch [47] assigned monetary importance levels to impact categories; Cadena et al. [28] suggested using both Type I and II approaches: Type I to identify the hotspots of the system, and the Type II to connect social indicators and stakeholders; Sawaengsak et al. [51] presented a weighted aggregation method using a cause-effect chain analysis; Souza et al. [54] suggested an impact method focusing particularly on workers' human development.

Concerning the stakeholders, Workers was the most studied with about 93%, followed by Local Community (70%) and Society (58%) (see Fig. 10). Consumers are the least studied in the sample, and Children, introduced in the updated Guidelines, was not explored. Other stakeholders considered (different from Guidelines) were Policymaker [29], Farm Owners [51,56], Suppliers, Shareholders, and Authorities [28]. Social concerns of bio-based systems are mainly restricted to employment issues, which although they are relevant to organisational performance, left behind social concerns with wider potential effects on the population.

Multiple subcategories or social themes were evaluated in the sample. First, focusing on the Guidelines subcategories (see Fig. 11), Health & Safety in Workers stakeholder is the most studied of the 40 themes. Other relevant subcategories for this stakeholder are Equal opportunities/Discrimination, Fair Salary, and Child Labour. In addition, Safe & Healthy living conditions and Local Employment appears as the most evaluated themes in the Local Community stakeholder. In the Society stakeholder, the themes that highlighted were Contribution to Economic Development and Public Commitments to Sustainability. When Consumers were considered, Health & Safety, Transparency, and Feedback Mechanism were studied. Finally, Fair Competition, Supplier Relationships and Promoting Social Responsibility were the themes addressed in Value Chain Actors. Regarding the use of the SHI score, all impact categories were considered once SHDB was applied. From the themes available in this method, those associated to Labour Rights and Decent Work impact categories were the most evaluated (see Fig. 12). In addition, some themes such as "Access to Electricity" and "Property Rights" in Community and "State of Environmental Sustainability" and "Poverty & Inequality" in Human Rights were not explored.

Themes addressed have been mostly connected to socio-economic aspects (e.g., economic development, fair competition), and focused on employment issues (e.g., salary, working hours, health and safety). This is also identified in Vance et al. [79] and Ferreira et al. [11], who observed that the social analysis of bioeconomy is associated with the assessment of employment issues, mainly. Hence, attention to social

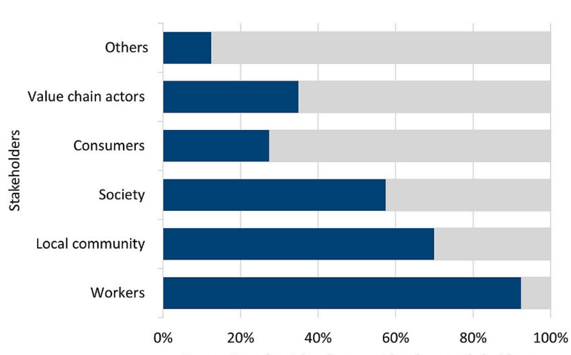

Fig. 10. Distribution of stakeholders evaluated.

issues such as corruption, poverty, respect for indigenous rights, and ethical treatment of animals, which are related to a wider scope of people (local community and society stakeholders), is in debt. Understanding how bioeconomy could affect a large population is a challenge to address. Furthermore, some social themes require more transparency in their evaluation. For example, discrimination/equal opportunities subcategory can address topics like incidents of discrimination (about sex, race, or age), policies for equal opportunities or gender equality. However, a scarce mention to the specific issue addressed in this subcategory was identified in the sample. Only three articles mentioned, specifically, topics associated with gender issues: gender equality (workers hired regardless of gender) and non-discrimination (equal wage) [51]; gender salary gap and women in labour force [57]; and gender equality (female employees and female in management position ratios) [26]. The women's role in bioeconomy requires further attention for the promotion of fair opportunities, whether this framework wants to represent an alternative to reach Sustainable Development Goals (SDG) (i.e., SDG 5: gender equality). Furthermore, the end-of-life is a critical stage to conserve suitable properties and characteristics of products that will recover in the production process. In this sense, how organisations provide proper information to consumers related to end-of-life options will be an essential aspect of the development of bioeconomy. Transparency toward consumers (e.g., through labels) to provide information about product characteristics and suitable recycling options will be helpful.

A significant diversity of new social themes was proposed, because of diverse sources where data was obtained (panel of experts, scientific articles, reports, etc). For example, Weldegiorgis and Franks [34] evaluated land use, employment, and workplace health & safety, based on the related studies and issues identified by stakeholders representative at local and regional scale. Some of these themes were land rights, appropriate working equipment/tools, respect for people of faith, mental health, tax evasion, energy security, household income, among others (see Table 2). Nevertheless, there are also some synergies and overlaps in these social themes proposed regarding the main topic evaluated. For instance, the concept of knowledge receives attention in aspects such as capital, access, transfer, and development. Technology is interesting in terms of transfer and development, as well as the security concept is associated to energy and food. Finally, income concern (household and net) is also proposed, but this could be similar to fair salary or wage assessment already presented in the UNEP Guidelines and SHDB database, respectively.

6.4. *Identified aspects in the interpretation analysis stage*

Only Do Carmo et al. [44] addressed the uncertainty issue for results robustness, analysing the scoring and weighting factors of the value judgment of experts. However, no other studies performed an uncertainty analysis as it is recommended by both Guidelines. Scenario analysis (what is likely to happen) and sensitivity analysis (the influence of options and assumptions on outcomes) were also not addressed. Furthermore, the materiality principle is not followed either, perhaps due to the recent publication of the Updated Guidelines.

The growing awareness of the effects of the climate change crisis and the urgent achievement of low-carbon economies motivates the preference of consumers for sustainable products. How easily communicate social impacts determined through S-LCA in a bioproduct promotion context can be the coming debate. Nowadays, S-LCA is not a prerequisite for social labels and claims [14], however, it could be expected that future social product declarations will align with product category rules (PCRs), as occur with the existing environmental PCRs.

7. Weaknesses and issues for future S-LCA studies

In this manuscript, a progress overview of the life cycle point of view in the calculation of the social effects of bioeconomy is provided. In this

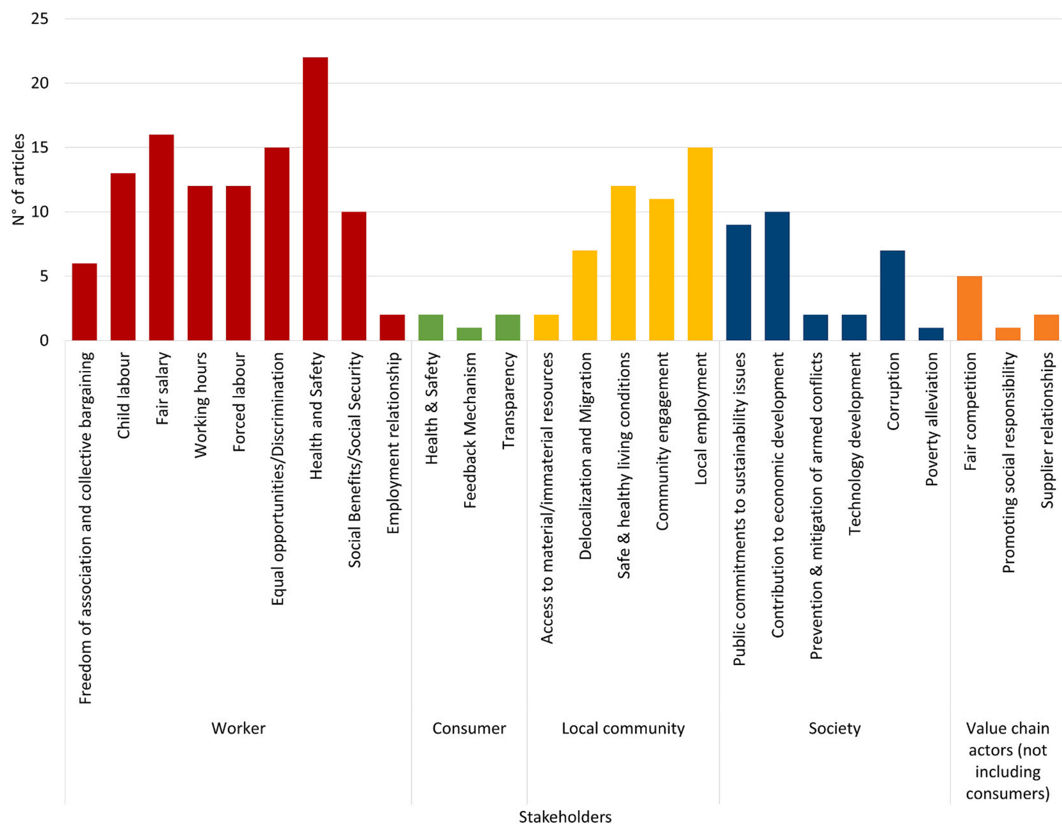

Fig. 11. Subcategories evaluated based on both Guidelines.

sense, it was observed this methodology is still in its beginning stage but evolving, due to the growing interest in its application. Different difficulties in methodological aspects may motivate future research in the search for a sound and comprehensive social assessment. The main weaknesses and, consequently, the challenges to be faced may be:

i. Absence of correlation between the FU and results, due to difficulties in FU definition as suggest both Guidelines.
ii. Lack of clarity in the system boundary definition and, the missing declaration of cut-off criteria.
iii. Scarce use of activity variable. Only seven articles mentioned the concept, four of them used it and three articles considered it for their framework proposal. In this sense, the decision to use an activity variable or not should be documented in the goal and scope phase as suggested by both Guidelines.
iv. The multifunctionality concept is not addressed, as well as possible allocation issues. This is relevant in multiproduct bio-based systems (e.g., biorefinery platforms). Only Souza et al. [45] declared allocation issue, meanwhile Tavakoli and Barkdoll [29] referred to allocated social scores to each stakeholder.
v. The major interest related to labour issues for evaluating Worker stakeholder. A reason behind this could be associated to the easier access to data related to this stakeholder, since the related information is mainly quantitively (e.g., working hours, salary, number of accidents, etc). The counterpart is Consumers with the lowest participation in the sample (26%), maybe because this stakeholder would require a more demanding data collection process (i.e., surveys) to obtain a representative sample. This stakeholder could be interesting to be evaluated specially for new bio-based products in the market. Children was not considered possibly due to the recent publication of the Updated Guidelines. Thus, more efforts should be put on diversify the stakeholder categories evaluated.
vi. Significance of the selection of social themes. Many articles declared follow the Guidelines or Updated Guidelines, however, when the impact assessment phase was performed, social themes selection was based on experts' or stakeholders' opinions, data availability, or previous studies. Although this can be also a positive aspect because of the interest in incorporating new social issues, the standardisation and convergence towards a defined set of impact categories (such as the E-LCA method) are still in debt.
vii. Although an important number of articles select the Type I method, there are an absence of consensus and standardisation in the impact methods. It can be expected that the SHI score (the second most used) obtains more relevance with the progress of the SHDB database. The absence of declaration about the type of impact method followed is not recommended due to results transparency. Furthermore, a scarce use of the Type II approach was identified, similarly to a state of the art about S-LCA in the agri-food sector [80]. Thus, more research that propose characterisation models for a comprehensive and quantitively impacts assessment are necessary.
viii. There is only one study that paid attention to positive social impacts assessment. Therefore, discussion about identifying, assessing, aggregating, and interpreting them could be helpful.
ix. Absence of development in uncertainty issues. This is quite relevant when indicators are evaluated, for example, through scoring system (Type I).
x. No sensitivity analysis was also identified in this review, which is suggested by both Guidelines.
xi. The need for social databases: 13 studies used SHDB and two applied PSILCA. Thus, efforts for elaborating more datasets that allow considering background processes in system boundaries are essential. This will allow more practitioners to start to apply this methodology.

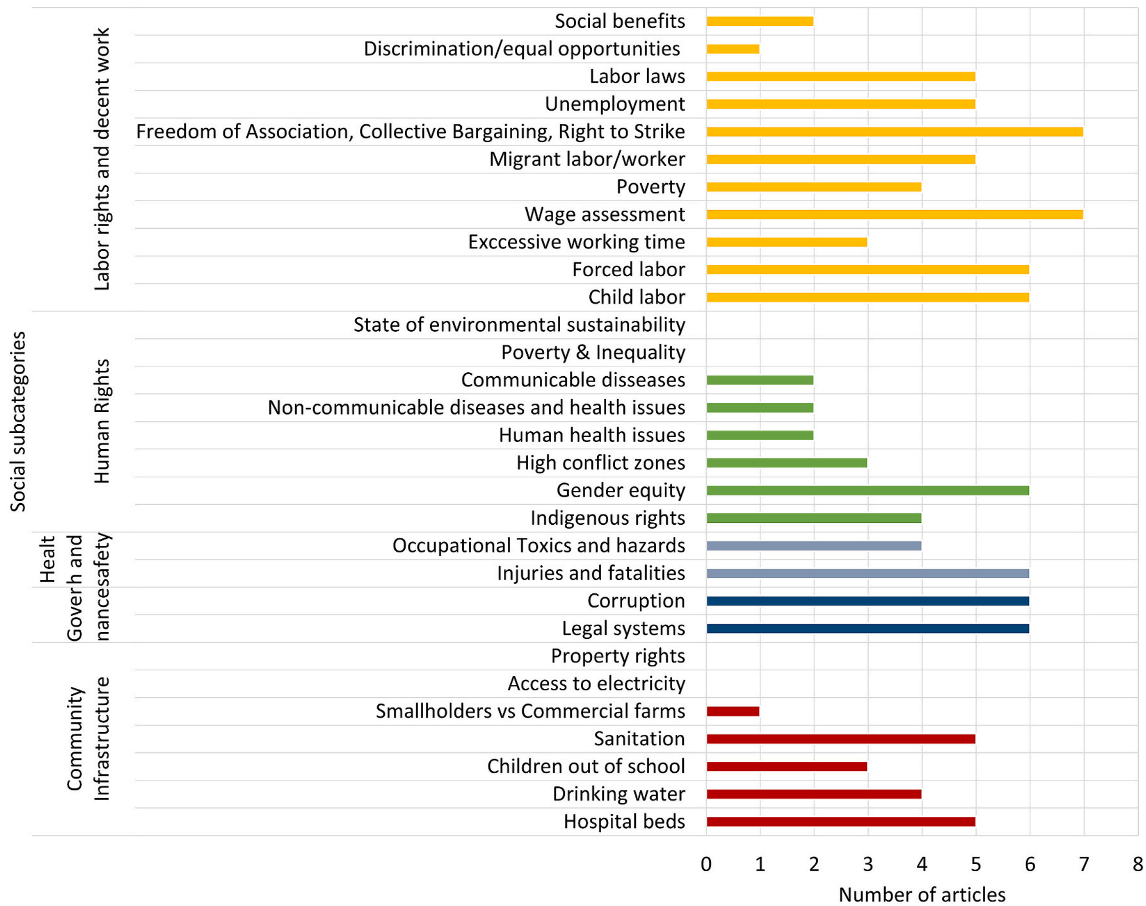

Fig. 12. Subcategories evaluated through SHDB database.

xii. In LCSA studies, an equilibrium in the methodological information of each dimension should be promoted for transparency of the results. How to aggregate these perspectives, currently handle by the Multicriteria Decision Analysis (MCDA) approach, is still under debate.

8. Is S-LCA sufficient to support the societal transition to the bioeconomy?

Society needs to move towards low carbon dependency to face the urgent climate crisis, and the bioeconomy is a key strategy to address it. At this point, it is relevant to ask whether the S-LCA methodology can support the transition to a bioeconomy from a societal perspective. Based on the current state of the art, the methodology is still in progress, and the topics considered are largely limited to labour issues (e.g., wages, employment, working time, health and safety at work). Thus, social norms and values, social entrepreneurship, or attitudes of the population, were not taken into account in the S-LCA methodology, as also was identified by Sanz-Hernandez et al. [82]. Furthermore, how to regulate this field as well as the role of decision-makers should be considered as the main aspects to be tackled in this transition [81].

In this regard, S-LCA considers different types of stakeholders in the assessment of potential social impacts, however, there is a need for this approach to take a broader focus. Currently, there is a partial view due to the emphasis on the production side, which is identified as the main objective of the methodology (Guidelines are proposed from product and organisation perspectives). Consequently, the implications for other components of society (e.g., consumers or the general public) have been less explored. The inclusion of smallholders (e.g., farmers), as a new stakeholder in the updated Guidelines, allows for the consideration of actors from the agricultural and forestry sectors, broadening the range of actors involved, which in this case, are fundamental to assess the social implications of the bioeconomy. In addition, a key actor that can promote bioeconomy is the public sector that addresses strategies in national and/or regional contexts [86]. However, the updated Guidelines do not consider this stakeholder and the SHDB method contains only two subcategories: legal system and corruption. It could be interesting to introduce social issues related to how governments promote these strategies and support the continuous improvement of this framework. Furthermore, the lack of social concerns from a customer perspective makes it difficult to understand the behaviour of society to internalise the need for sustainable development.

The transition of socio-technical systems implies changes in modes of production and consumption as well as in infrastructure and technology aspects [83]. Thus, moving towards a bioeconomy framework requires greater attention to the context in which new technologies, bioenergy systems and bioproducts are expected to be developed. Bio-based systems will be part of a complex web of interactions and collaborations in multi-level perspectives [84]. Similar to an innovation system, the success of the bioeconomy will depend on changes along the value chain and social processes in which multiple actors (e.g., society, government, science, and industry) will interact [84]. To do so, companies and organisations should converge their visions (i.e., expectations, beliefs, and strategies) in a direction towards a balance between economic growth and ecological integrity. Nevertheless, the assessment of the characteristics and dynamics of these groups was not addressed in the studies analysed. Furthermore, although some regional analyses based on specific bioresources have been addressed (e.g. Ref. [25]), a global perspective was not found. This is relevant due to the need for analysis related to how to implement bioeconomy strategies and regulations in a

Table 2
Other social themes or subcategories evaluated in the sample.

Reference	Social themes	Reference	Social themes
[25]	Knowledge capital (society), Equal opportunities (society), Participation (workers)	[29]	Household Income, Food Security, Resource Conservation, Social Acceptability, Effective Stakeholder Participation, Risk of Catastrophe, Visual Impacts
[47]	Minimum wages set according to legal framework, Appropriate working equipment/tools, Economic growth and development (including reduction in unemployment), Use of environmentally friendly (green) products in technology upgrades, Respect for people of faith, Cultural diversity, Consumer satisfaction practices, Benefits for an employee's family, Mental health, Pollution level in workplace	[62]	Energy security, External trade, Resource conservation, Technology development, Relationships between chain members, Bioenergy quality
[49]	User value, Economic development, Capacity building, Infrastructure development, Tax evasion	[66]	Training, Expertise, Public participation, Sustainable behaviour, Social acceptance, Demand satisfaction,
[56]	Land tenure of farmers, Net income from selling product, Employment generation, Working conditions and standards	[64]	Public Awareness, Location, Public Acceptance, Government Policy, Improved Sanitation, Improved Electricity Supply, Income
[28]	Labour Practices and Decent Work, Human Rights, Society, Product Responsibility	[55]	Knowledge and skills development, Job satisfaction
[51]	Land rights; Access to knowledge, facility, and natural resources; Gender equality; Capacity development; Fair access to means of production; Quality of life	[36]	Physical working condition; Sustainable development; Quality, safety, and environmental standards
[59]	Human health impacts, Large accident risk, Energy security, Nuclear proliferation, Intergenerational equity	[38,40,41]	Transparency on social/environmental issues, Food Security, Horizontal conflict, Transfer of technology and knowledge
[53]	Availability of resources, Knowledge and skills development, Consumer savings, Responsibility for technology use, Existence of infrastructure for the technology, Health and safety regulations, Energy efficiency of the technology	[39]	Obesity, Large land holdings, Life expectancy

global context [82].

On the technological side, S-LCA can support the evaluation through subcategories such as "Technology Development" to assess if organisations are engaged in research and investments on new technologies; or "Respect of Intellectual property rights" to identify actions to safeguard and value creators of intellectual goods and services. Although financing technologies is one of the constraints identified in national bioeconomy strategies [85], this issue has hardly been addressed in the state of the art with only two manuscripts. Furthermore, the sectors associated with the bioeconomy are, in general, highly male-dominated, and the transition may not ensure that these inequalities are reduced or addressed [87]. Here, S-LCA can support the assessment of gender equality and discrimination issues, but no significant reflection on this issue was observed in the sample analysed.

Finally, to respond to the question of whether S-LCA is enough to support the social transition towards a bioeconomy, the answer is yes, albeit partially. Although this approach contains aspects that can be valuable to support the assessment of the social implications of bio-based systems (e.g., gender equality, labour issues, technological development, property rights), the transition requires the attention of multiple dimensions of society and influences factors (e.g., government policy, regulatory conditions, intellectual property rights, human resources, social acceptance and market structure) [88]. The different actors involved, and their interactions make the social assessment of the bioeconomy a major challenge. The S-LCA methodology should pursue broader attention to social interactions that drive efforts towards sustainable development of the bioeconomy.

9. Conclusion

Bioeconomy is promoted as a sustainable strategy for the reduction of fossil-based resource consumption under the emergency scenario of the climate crisis. Although the sustainability analysis of bio-based systems is primarily concentrated on economic and environmental dimensions, the social perspective starts to attract the attention required. The S-LCA methodology appears as a promising and helpful tool to measure the potential social effects of bioeconomy strategies. However, it was identified that this tool is still evolving, and further research is needed to consolidate it as equal to the environmental and economic life-cycle perspectives. The initial pathway towards this goal has begun with the Guidelines standardisation principles, the methodological sheets for social themes, the recent pilot tests performed by the Life Cycle Initiative, and the progress of robust databases. Policies promotion will also motivate further research interest in the social perspective for a properly sustainability assessment of bioeconomy. Currently, the research has been focussed on topics such as introducing positive social impacts and new indicators, initial debate on uncertainty assessment in scoring systems, protocols to collect inventory data and identification of stakeholders, or how to evaluate production processes at an early stage of the design, among others. Moreover, the social analysis in bioeconomy has been focused mainly on bioenergy systems (specially biofuels production), and social themes associated with job issues. Methodological deficiencies reflect the initial pathway of this tool such as those related to boundaries definition, cut-off criteria, multifunctionality, data availability, impact assessment methods, uncertainty, and results interpretation. In this sense, further studies could address these issues, along with more attention to those stakeholders, social themes, and bio-based strategies (biorefineries, wastewater resources recovery systems, bio-based products, etc) less explored.

S-LCA can plays a relevant role as a support methodology to address social issues in the advancement of the bioeconomy, and the socially responsible implementation of a variety of bio-based strategies. Thus, it is relevant that future studies follow the principles of transparency, reliability, and relevance. For this, the Updated Guidelines are a promising and valuable starting point to facing these challenges.

Credit author statement

Ricardo Rebolledo-Leiva: Conceptualization, Investigation, Methodology, Software, Writing–original draft preparation, Visualization. **María Teresa Moreira**: Supervision, Reviewing and editing, Visualization. **Sara González-García**: Supervision, Reviewing, and editing, Visualization, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr. Sara González-García, one of the authors of this paper is one of the Guest Editors of the Special Issue VSI: Sustainable Bioeconomy of RSER. She was blinded during the review process and the paper was handled by another Editor.

Data availability

Data will be made available on request.

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