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Systematic Review

Life cycle sustainability assessment of the agri-food chain: empirical review and bibliometrics

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Abstract

Paper aims: This study aims to identify the advances in the literature related to Sustainable Life Cycle Assessment in the agricultural and food process sectors.

Originality: This study pioneers an investigation into trends in applying Life Cycle Sustainability Assessment techniques within the agricultural and food processing sectors, with a comprehensive consideration of environmental, economic, and social perspectives.

Research method: A systematic literature review and a bibliometric analysis revealed 71 articles that applied at least one of the life cycle assessment tools.

Main findings: The bibliometric analysis indicated that the studied areas have two main areas that separate studies in the food process sector and the agricultural sector areas. The content analysis indicated that most studies apply the environmental assessment of the life cycle, coupling some studies with the economic and social view and mainly using an attributional approach with the scope ranging from the cradle to the grave regarding the area.

Implications for theory and practice: As for theory, this study includes advancing knowledge and filling a research gap, while the practical relates to more sustainable decision-making by professionals involved in the agricultural and food processing sectors.

Keywords

Life cycle sustainability assessment. Agriculture. Food process. Farm. Impacts.

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1. Introduction

The growth of consumption in domestic and foreign markets and the demand for higher quality constitute challenges for world production (Graciano et al., 2022; Rossi et al., 2024), especially in the food sector (Marques et al., 2021; Lermen et al., 2022; Matias et al., 2023). Generally, it is necessary to reduce external commodities with minimal environmental impacts in variable climatic conditions (Zhang et al., 2020). In this scenario, the production of agricultural and food commodities has a relevant influence on the world economy, with an estimated contribution of US$ 1.109 trillion (2019) to the world's Gross Domestic Product (GDP), corresponding to a share of 5.2%. However, in practical terms, agriculture's overall contribution to world GDP is more significant than this percentage, as it is indirectly related to sectors such as food and beverage manufacturing, which need agricultural inputs for their production (United States Department of Agriculture, 2020).

According to the United Nations Food and Agriculture Organization (FAO), the estimated global volume of food waste is 1.6 billion tons of raw materials per year, equivalent to just over 25% of all food produced worldwide (Ilakovac et al., 2020; Luz Peralta et al., 2020). The growing amount of waste grain is a concern in the agricultural sector, mainly in post-harvest processes (Lermen et al., 2020, 2023a). These residues occur in food processing and post-harvest (Armington et al., 2020; Ilakovac et al., 2020; Lermen et al., 2018). Thus, food waste becomes worrying, given that it is accompanied by water, energy, and soil losses, increasing the need to reduce the impact of human behavior on the ecosystem (van Geffen et al., 2020; Matos et al., 2022).

Agricultural and food processing residues are generally rich in carbon and nitrogen sources, such as carbohydrates, proteins, and lipids. Through different optimized bioprocesses, these elements are excellent industrial inputs for the bioconversion of high-value bioproducts, such as biofuels, enzymes, probiotics, bioactive compounds, or even biodegradable plastics (Ascher et al., 2020; Bergström et al., 2020). Thus, given its chain relevance, quantifying waste impacts in these sectors requires the use of tools capable of evaluating the effects of their processes on social, environmental, and economic sustainability.

The Life Cycle Sustainability Assessment (LCSA) technique can be considered appropriate for assessing total sustainability in the agricultural and food sectors, including the Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle (S-LCA) (De Luca et al., 2018). According to the UNEP/SETAC Directive (United Nations Environment Programme, 2012), the LCSA involves four steps, similar to the environmental LCA, namely: i) definition of objective and scope, ii) life cycle inventory analysis, iii) impact assessment and (iv) interpretation, which provide a starting point for measuring sustainability, based on three life cycle assessment techniques:

LCA: a predominant technique for evaluating the environmental performance of processes, with studies, carried out to assess the impacts on the environment, considering the energy, raw material, and production needs (De Luca et al., 2017).

LCC: technique focused on the economic area that supports decision-makers in identifying the least economically impacting measure among competing alternatives. The costs associated with a particular product, service, or process can be divided into capital, consumption, operation, and maintenance (Moslehi & Reddy, 2019).

S-LCA: Technique for the social component of sustainability, which makes it possible to understand the involvement of employees in the various stages of the product and system life cycle. This technique assesses stakeholders' positive and negative social impacts throughout a system or product (Fortier et al., 2019).

Suitable techniques for sustainability assessment, such as those based on Life Cycle Management (LCM), have broad applications for product comparison and optimization (Arushanyan et al., 2014; Del Pero et al., 2017). These techniques also provide potential in the environmental, social, and economic evaluation of products, services, and processes, reducing impacts in various activities. In this sense, using the LCM can lead to technical and managerial decisions that support the farms' technological, economic, and social development based on optimizing resources and properly managing their operations. Other topics must be evaluated in this area, such as innovation, entrepreneurship, and risk (Teixeira et al., 2022; Graciano et al., 2023; Lermen et al., 2023b).

Previous studies evaluate LCSA applications through a general review (Alejandrino et al., 2021), a review of system thinking (Onat et al., 2017), and a review of barriers to LCSA implementation (Troullaki et al., 2021). Generating a lack of studies that evaluate the agri-food sector. Concerning this lack, this study presents a research question: How LCSA is treated in the agricultural and food processing sectors? Given this question, this study aims to identify trends in the literature related to the agricultural and food processing sectors in applying the LCSA technique, considering the different perspectives: Environmental, Economic, and Social.

This study presents a triad of contributions, as theoretical, evaluated 71 papers related to LCSA applications in the main sectors related to agri-food sectors. As for methodologies, this study employs systematic literature review and bibliometric analysis using advanced protocols and software. Finally, as empirical contributions, the total studied sample is empirical, so the evaluation presents practical studies that support decision-makers in the agri-food sector.

2. Theoretical background

Regarding the LCSA, the seminal study is that of Klöpffer (2008), with 728 citations. The authors state that LCSA has been neglected in the past, in which the main problems are quantifying social indicators (S-LCA). The combination of LCA, LCC, and S-LCA can provide a tool for evaluating product sustainability (Klöpffer, 2008).

Among the central studies that implemented the LCSA are Atilgan & Azapagic (2016), with 178 citations, in which they evaluated the impacts on electricity generation in Turkey; Ren et al. (2015), with 159 citations, assessed the best ways to produce bioethanol in China through the LCSA.

As for LCA, the seminal study is that of Finnveden et al. (2009), with 2189 citations, in which they provided a review of LCA methods. Another analysis is that of Rebitzer et al. (2004), with 1380 citations, which presents the structure and procedure of LCA, which describes how to define and model the life cycle of a product and provides an overview of the methods and tools available to tabulate and compile associated emissions and resource consumption in a life cycle inventory. The most cited applications are Lardon et al. (2009), with 1173 citations evaluating biodiesel production by microalgae, and Hawkins et al. (2013), with 1008 citations assessing the impacts of electric vehicles.

Concerning LCC, Gluch & Baumann (2004), with 365 citations, discussed theoretical assumptions and the practical usefulness of the LCC approach in making environmentally responsible investment decisions. The authors report that three research solutions are proposed to address these inconsistencies in the future development of environmental decision support tools. Another review study was developed by Korpi & Ala-Risku (2008) with 162 citations, in which reports on LCC applications were reviewed to provide an overview of LCC uses and implementation feasibility. The most cited empirical work is that of Luo et al. (2009), with 253 citations; they evaluated the environmental and economic impacts of generating bioethanol from sugar cane in Brazil.

Finally, as for S-LCA, Jørgensen et al. (2008), with 376 citations, evaluate S-LCA methodologies. The authors indicate that several methodological proposals argue that social impacts are linked to the conduct of the application site, leading to the conclusion that each stakeholder must be evaluated. Benoît et al. (2010), with 338 citations, developed guidelines that demystify the assessment of the social impacts of the cycle and present a practical structure that represents the consensus of an international group of experts who lead research in this area. Regarding applications, Martínez-Blanco et al. (2014), with 183 citations, in which they identified the challenges of fertilizer S-LCA and also, and Manik et al. (2013), with 153 citations, in which they evaluated the social impacts of palm oil biodiesel production in Indonesia.

3. Methods

In terms of aims, this research is classified as exploratory descriptive, aiming to explore and describe the state of the art in Life Cycle Sustainability Assessment of the Agri-Food Chain through literature review and data analysis. In terms of nature, this research is categorized as basic research, as it involves a literature review on the applications of studies related to the Life Cycle Sustainability Assessment of the Agri-Food Chain. Regarding the approach, this research is classified as qualitative-quantitative, as data from articles on the topic were collected and analyzed, and characteristics of the sample studies were discussed."

A Systematic Literature Review (SLR) was used to manage the diversity of available knowledge and allow researchers to assess cutting-edge knowledge and specify research questions (Kuakoski et al., 2023; Ramos Cordeiro et al., 2024). This study followed the steps Tranfield et al. (2003) proposed, which delimit specific principles to be applied in the search, classification, and interpretation of findings.

SLR enhances the legitimacy of the results (Tranfield et al., 2003), providing a reliable basis for formulating hypotheses and setting direction for future studies. SLRs should also identify essential contributions in a specific area of research (Denyer & Tranfield, 2009). Assessments are generally conducted using an iterative cycle of defined keywords, searching the literature, and analyzing (Rousseau et al., 2008; Saunders et al., 2019). To carry out this study, the SLR was structured in three stages: i) selection of studies on the topic (results of the research), ii) analysis of statistical data, and iii) content analysis (Denyer & Tranfield, 2009).

The study selection step (i) was based on the Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method, proposed by Moher et al. (2009). In data analysis (ii), the bibliometrix package was used with the R software, an open-source language. The bibliometrix package (http://www.bibliometrix.org) is an algorithm written in the R language that provides tools for quantitative research in bibliometrics. Data collection using the bibliometrix package makes it possible to analyze data from the central scientific databases, such as Scopus and Web of Science, which were chosen for the research because they are the most extensive databases compatible with bibliometrics for the area. In turn, content analysis (iii) followed the steps suggested by Elo & Kyngäs (2008): open coding, categorization, and abstraction. Relevant information was identified in a deductive process through these steps, based on coding in the communities studied. This information was analyzed in two ways: (i) bibliometric analysis and (ii) content analysis of empirical studies for each community. Finally, the abstraction step supported the discussions between the sample authors for each community.

In step i), the following search string was defined: ("Life Cycle Sustainability Assessment" OR "Life Cycle Assessment" OR "Social Life Cycle Assessment" OR "Life Cycle Costing") AND ("Agri-food" OR Agriculture OR Food); selecting empirical and theoretical studies to compose the sample. Using a five-year temporal sample (2017-2021), the search was performed in the Web of Science (176 identified articles) and Scopus (45 identified articles) databases. These databases cover many journals from different areas with relevant impacts. For analysis purposes, the 221 articles were inserted into the Mendeley© reference manager software; the selection process of these documents is shown in Figure 1, following the PRISMA protocol.

An Excel table was created to identify each article for article screening, and the corresponding article files were downloaded in BibTeX format. Articles excluded based on the PRISMA protocol were removed from the table, and their BibTeX files were deleted as in Figure 1.

For the selection process of the sample of articles, four reductions were carried out in the original sample of documents, as shown in Figure 1, and both theoretical and empirical studies were selected in the sample. The first reduction excluded three articles due to duplicity. In the second, 23 studies presented in books and conferences were excluded, and the sample became 195 articles. Before the third exclusion, ten articles were added that had the theme but were not found in the search in the snowball stage, so the sample became 205 articles. The third reduction was performed from reading titles and abstracts, excluding 128 articles out of the research scope; the sample was reduced to 77 articles. The fourth and final reduction dealt with the reading of abstracts, with six articles excluded because they were out of scope or part of literature reviews. A complete reading of 71 articles were then carried out, being evaluated by the publication journal, the impact factor (InCites Journal Citations Report - 2020), citations (Scopus - 2020), LCM technique used, scope, allocation approach, method of impact assessment, application area, and trends. Six articles were excluded after full reading at this stage, as they did not present relevant information for the study. During the scope reading, the snowball method was applied in search of more studies that would contribute to the portfolio of this review. At this stage, ten additional studies were identified. Together with the previous ones, these were evaluated and totaled a portfolio of 71 articles.

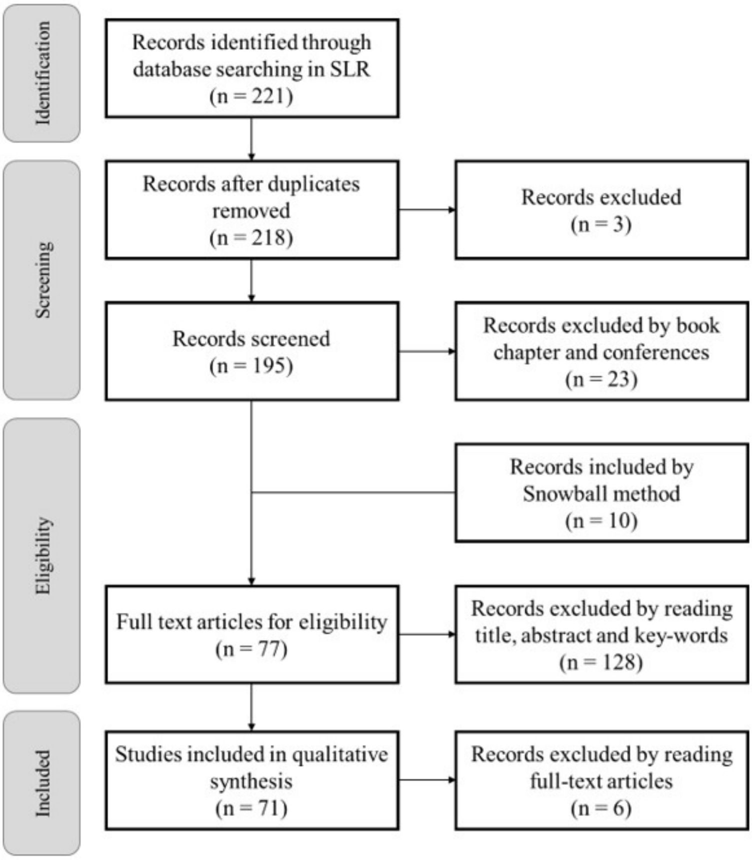

Figure 1. PRISMA method for sample selection. Source: Moher et al. (2009).

These studies were then analyzed concerning the LCSA in agriculture and food processing. The analysis then focused on studies that assess these sectors' environmental, economic, and social impacts. Research trends and gaps in studies on LCSA in the considered sectors were also identified and analyzed. These trends and gaps are presented as opportunities for future studies.

4. Results

Based on the results of the 71 selected articles, this section initially presents the bibliometric analysis and the content analysis performed.

4.1. Bibliometric analysis

Appendix A presents the annual production of studies related to the content of this review and the journal, country, and authors with the highest number of publications. It is noted that production on LCA studies has increased over the years, gaining special attention recently, starting in 2017. Most of the studies originate from Italy, followed by Australia and Sweden. The Journal of Cleaner Production concentrates on the most significant number of publications (Appendix B). Appendix C shows that several authors started publishing in 2017 and 2018, some with a significant volume of production and citation, others with a high production volume but not as cited, and some with productions and citations in the same average. As for the authors with the highest number of publications and citations, it is observed that only one author (Biswas) kept his publications and citations constant during the period (Appendix D). Figure 2 presents the most used keywords in the studies accumulated.

Considering Figure 2, the most cited accumulated keyword was Life Cycle, that is the main the studied by authors; followed by Waste Management, Food Waste, Sustainability, Sustainable Development, and LCA. As mentioned, publications and citations, in all keywords grow from 2017. In Figure 3, the dendrogram that groups such citations is shown.

The dendrogram was able to reveal two main clusters. In general, these two clusters characterize the two application sectors. Blue represents citations predominantly associated with the food processing sector, and red represents the agricultural sector. The bibliometrix also presents the behavior of related themes over the last few years, characterized by the growth of publications, as shown in Figure 4.

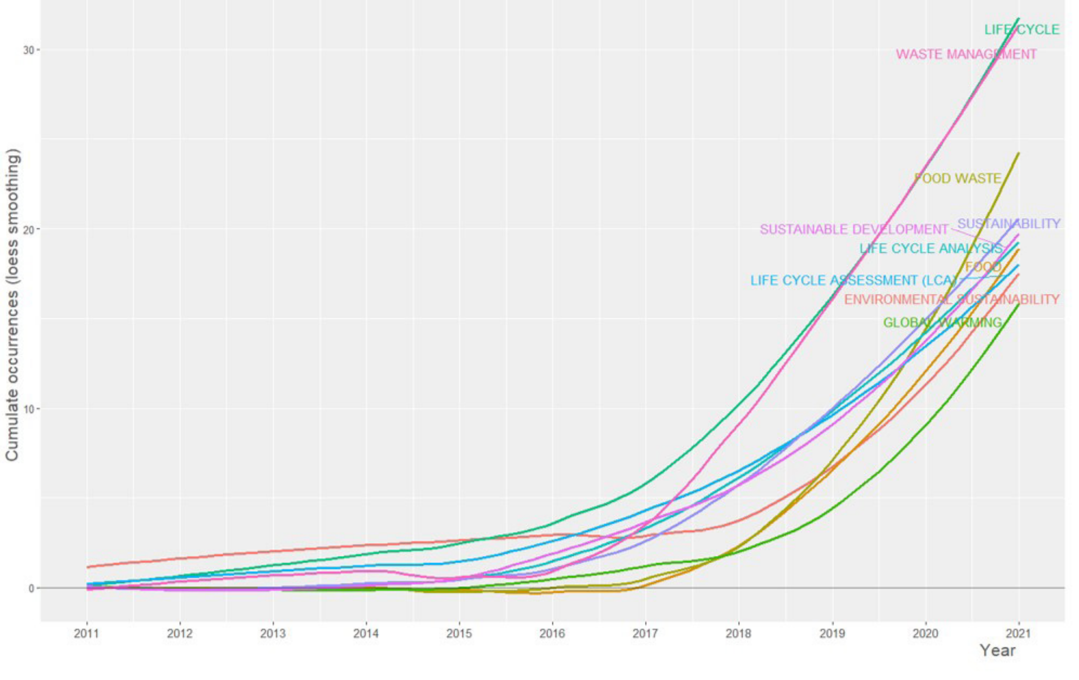

Figure 2. Most cited accumulated keywords.

The left side of the image shows how the themes emerged and were named, while the right side shows the current situation where they migrated. The theme that emerged as ‘environment’ migrated to ‘environmental impact’ and, specifically, to ‘eutrophication.’ Environmental sustainability became part of environmental impact, assessment, and life cycle themes. The topic of sensitivity analysis started to be also found in the environmental impact assessment specifically with eutrophication. The life cycle was incorporated into most themes, being present in sustainability and mainly in environmental impacts, eutrophication, and global warming. Finally, life cycle analysis began to encompass life cycle and sustainability. Subsequently, factor analysis was applied to identify common keywords in response to unnoticed (hidden) keywords, according to the conceptual structure map in Figure 5.

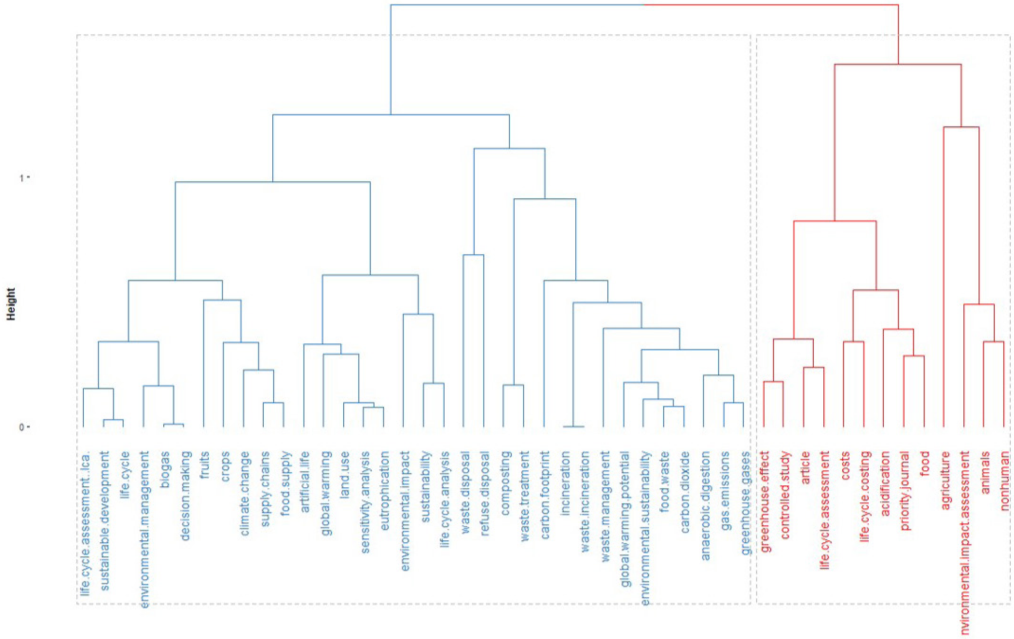

Figure 3. Dendrogram.

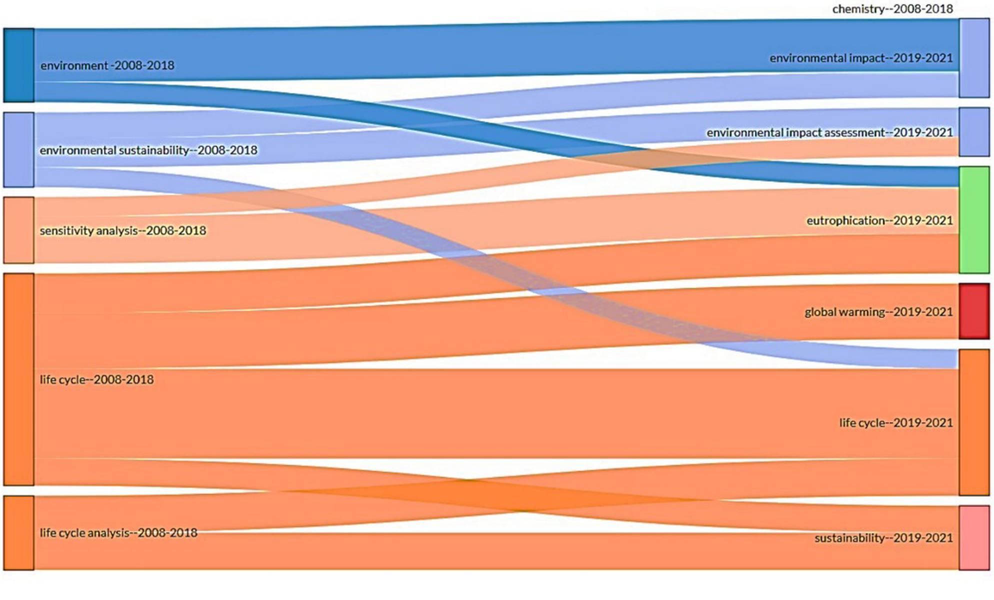

Figure 4. Behavior of the themes over years.

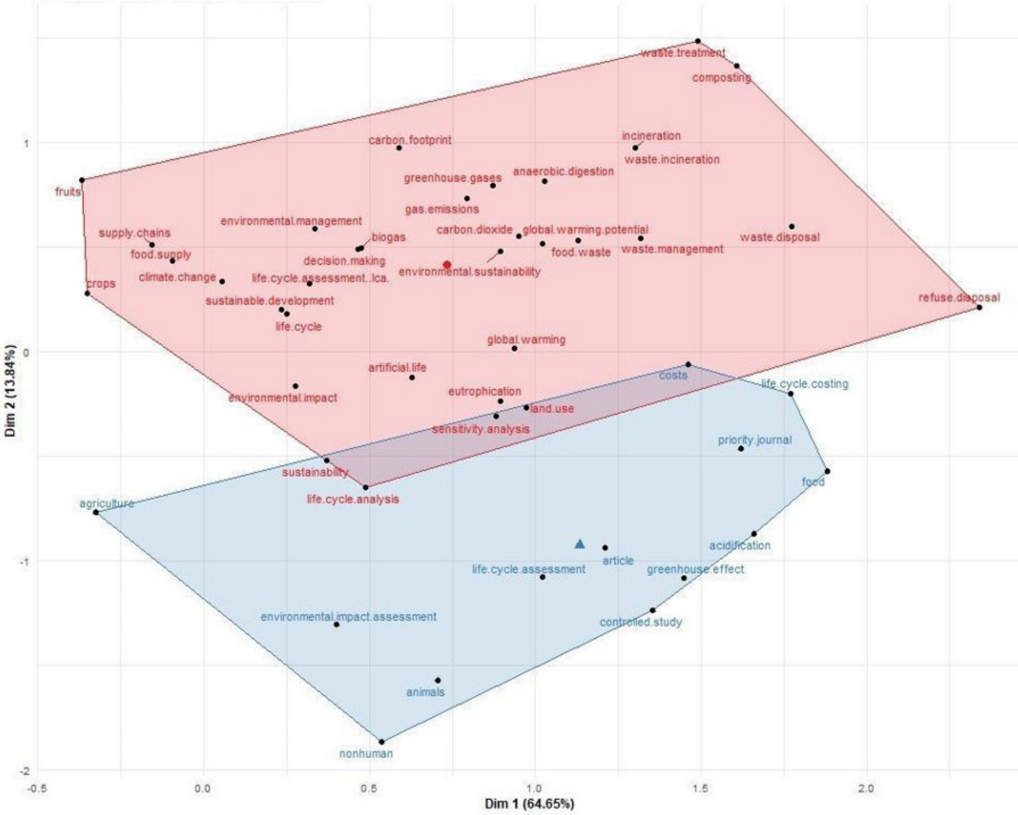

Figure 5. Conceptual structure map.

The parameters applied in the factor analysis (Figure 5) included multi-match analysis, with the analysis field being the keywords of the records, with automatic grouping. Figure 5 demonstrates the variability between the correlated keywords, seeking to find the latent factors that create similarity in the data records. This statistical method can identify the smallest number of underlying variables out of many observed variables.

The factorial analysis derives two keyword rankings (Figure 5). The blue classification represents agriculture, food, environmental impact assessment, LCC, controlled studies, etc. The classification in red represents more specific keywords such as fruits, supply chains, food supply, cultivation, carbon footprint, incineration, composting, food waste, and waste management. At the central point of Figure 5 are the five related keywords: sustainability, land use, sensitivity analysis, costs, and life cycle analysis. These keywords are applied to various studies related to specific analyses performed within the LCSA. In Figure 5, the clusters are inverted in color when related to Figure 3 (Dendogram), with the agricultural sector in blue and the food processing sector in red.

4.2. Content analysis

We sought to identify how the LCSA can be suitable for assessing sustainability in agricultural and food processing sectors and how these themes are presented in the literature. Table 1 presents these documents' journals, impact factors, and citations.

As verified in the bibliometric analysis, most of the studies come from the Journal of Cleaner Production (20 articles), about 28.2%. However, the topic was also published in other recognized journals. An example of a high-impact article in this area is the study by Brancoli et al. (2017), with 101 citations in the journal Resources, Conservation and Recycling. Table 2 presents the LCSA: the techniques used, approach, impact assessment method, scope, and application area.

Table 1. Journals, impact factors, authors, and citations of the study sample.

Journal	Impact Factor	Authors (year) - Citations
Agricultural Systems	4.212	Acosta-Alba et al. (2019) - 9
Resources	-	Bergström et al. (2020) - 5
Sustainability	2.592	Sanyé-Mengual et al. (2018) – 22
		Blanc et al. (2019) - 18
		Kim et al. (2020) - 7
		Roselli et al. (2020) - 3
		Gaspar et al. (2018) - 1
Journal of Cleaner Production	6.395	Cristóbal et al. (2016) – 36
		Angelo et al. (2017) - 34
		Benis & Ferrao (2017) - 54
		Noya et al. (2017) - 17
		Yang & Campbell (2017) - 91
		Salomone et al. (2017) - 13
		Sonesson et al. (2017) - 52
		Chiu & Lo (2018) - 134
		Tricase et al. (2018) - 23
		Lam et al. (2018) - 29
		Svanes & Johnsen (2019) - 2
		Alam et al. (2019) - 15
		Guven et al. (2019) - 7
		García-Herrero et al. (2021) - 2
		Nindhia et al. (2021) - 52
		Chen &Holden (2018) - 9
		De Luca et al. (2018) - 28
		Krishnan et al. (2020) - 44
		Longo et al. (2017) - 33
		Rosa et al. (2017) - 5
Science of the Total Environment	6.551	Castellani et al. (2017) - 37
		Cancino-Espinoza et al. (2018) - 6
		Parajuli et al. (2018) - 55
		Konstantas et al. (2019) - 7
		Wohner et al. (2020) - 8
		Albizzati et al. (2021) - 4
Bioresource Technology	7.539	Edwards et al. (2017) - 66
		Smetana et al. (2017) - 70
		Edwards et al. (2018a) - 40
		Ascher et al. (2020) - 5
Innovative Food Science and Emerging Technologies	4.477	Cacace et al. (2020) - 12
Resources, Conservation and Recycling	8.086	Brancoli et al. (2017) - 101
		Edwards et al. (2018b) - 18
		Smetana et al. (2019) - 69
		Ulmer et al. (2020) - 4
The International Journal of Life Cycle Assessment	4.868	Warshay et al. (2017) - 88
		Dekker et al. (2020) - 6
Integrated Environmental Assessment and Management	3.440	Colley et al. (2020) - 3
Frontiers in Sustainable Food Systems		Elginoz et al. (2020) - 2
		Winans et al. (2020)
Waste Management	5.448	Fieschi & Pretato (2018) - 15
Journal of Food Engineering	4.499	Garofalo et al. (2017) - 26
Food Research International	4.972	Gutierrez et al. (2017) - 32
Environmental Science & Technology	7.678	Núñez & Finkbeiner (2020) - 2
Applied Soil Ecology	3.187	Pergola et al. (2018)
Agronomy	3.187	Pergola et al. (2020)
Agroecology and Sustainable Food Systems	1.636	Persiani et al. (2021)
Aplied Sciences	2.474	Salwa et al. (2020)
Future of Food: Journal on Food, Agriculture and Society	0.28	Sanyé-Mengual et al. (2017)
Journal of Applied Phycology	3.016	Schade et al. (2020)
		Schade & Meier (2020)
Journal Pre-proof	3.016	Slorach et al. (2020) - 12
Acta Horticulturae	0.52	Stillitano et al. (2017) - 2
Renewable and Sustainable Energy Reviews	12.110	Sun et al. (2019) - 17
Applied Energy	8.848	Tong et al. (2018) - 41
Frontiers in Veterinary Science	2.245	Verduna et al. (2020) - 1
British Food Journal	2.102	Vinci & Rapa (2019) - 8
Journal of Environmental Management	5.647	Yeo et al. (2019)
		Kuhn et al. (2018) - 3
Energy Policy	5.042	Yuan et al. (2018) - 25
Chemical Engineering Journal	3.475	Zhang et al. (2020) - 7
Applied Engineering in Agriculture	0.740	Alanya-Rosenbaum et al. (2018)
Ecological Indicators	4.490	Schüpbach et al. (2020)

Note: Citations were assessed in June 2021 based on Scopus (2022).

Table 2. Information related to the LCSA.

Paper	Technique (LCSA, LCA, LCC, S-LCA)	Approaches	Impact assessment method	LCSA scope	Application area (field of study)
Acosta-Alba et al. (2019)	LCA	Attributional	IPCC	Crib at the gate	Family farming, including coffee, sugarcane, and small livestock production
Benis & Ferrao (2017)	LCSA	Attributional	GWP, IPCC, CF	Crib at the gate	Surplus food redistribution units in Sweden
Blanc et al. (2019)	LCA+ LCC	Attributional	externality assessment (ExA), GWP	Cradle to the grave	Use of Bio-Based Plastics in the Fruit Chain in Raspberry Supply Chains in Northwest Italy
Alam et al. (2019)	LCA	Attributional	GWP, IPCC	Cradle to farm gate	GHG emissions associated with monsoon rice production in intensive rice-based cropping systems in northwest Bangladesh
Albizzati et al. (2021)	LCSA	Attributional	IPCC, GWP	Cradle to the grave	Animal feed production
Ascher et al. (2020)	LCA	Attributional	GWP100, USEtox	Crib at the gate	Food waste management
Benis & Ferrao (2017)	LCA	Attributional	ReCiPe Midpoint	Industry gate to the grave	Food waste treatment
Cancino-Espinoza et al. (2018)	LCA	Attributional	IPCC 2013, ReCiPe 2008	Crib at the gate	Production, packaging, and distribution of organic quinoa
Cacace et al. (2020)	LCC + LCA	Attributional	ReCiPe Midpoint (H)	Industry gate (reception to dispatch)	Food processing
Chiu & Lo (2018)	LCA	Attributional	ReCiPe	Cradle to the grave	Treatment of sewage sludge and food waste
Castellani et al. (2017)	LCA	Attributional	ILCD 1.04, ILCD EU-27, CML-IA	Cradle to the grave	Food supply chains
Brancoli et al. (2017)	LCA	Attributional	ILCD	Cradle to the grave	Food waste
Edwards et al. (2018a)	LCSA	Attributional	IPCC, CML-IA Version 4.2	Cradle to the cradle	Management of food waste
Dekker et al. (2020)	LCA	Attributional	Recipe 2008, 2016	Cradle to plate	Food consumption
Cristóbal et al. (2016)	LCA	Attributional	ILCD, PEF (ECPEF)	Crib at the gate	Management of food waste
Colley et al. (2020)	LCA	Attributional	MICs, ReCiPe H	Crib to door	Sheep system in Australia
Edwards et al. (2017)	LCA	Attributional	CML-IA (version 4.2)	Cradle to cradle	Waste and wastewater treatment
Edwards et al. (2018b)	LCA	Attributional	IPCC, CML-IA, GWP	Cradle to cradle	Food waste, household waste
Elginoz et al. (2020)	LCA	Attributional	CML 2001	Crib at the gate	Domestic waste management
Fieschi & Pretato (2018)	LCA	Attributional	ILCD, PEF, IPCC	Cradle to the grave	Food processing
Garofalo et al. (2017)	LCA	Attributional	GWP100, ILCD 201	Cradle to the grave	Food processing
García-Herrero et al. (2021)	LCA + LCC	Attributional	EPD 2013	Cradle to the grave	Food waste
Lam et al. (2018)	LCA	Attributional	ReCipe Endpoint	Cradle to the grave	Food waste
Kim et al. (2020)	LCA	Attributional	CEDA, TRACI 2.1 Environmental Data Files	Cradle to the grave	Food diet
Maia Angelo et al. (2017)	LCA	Attributional	ILCD	Cradle to the grave	Solid food waste
Gutierrez et al. (2017)	LCA	Attributional	Endpoint ReCiPe	Cradle to the grave	Food packaging
Winans et al. (2020)	LCA	Attributional	ReCiPe Midpoint (H) 1.12	Cradle to grave, door to door, and gate to grave	Food processing
Guven et al. (2019)	LCA	Attributional	Recipe	Cradle to the grave	Management of food waste
Konstantas et al. (2019)	LCC	Attributional	GWP	Cradle to the grave	Food processing
Nindhia et al. (2021)	LCA	Attributional	PEF, diretrizes FPE	Cradle to the grave	Livestock production
Núñez & Finkbeiner (2020)	LCSA	System Expansion	SaltLCI located in the cause-and-effect chain	Cradle at the farm gate	Production of different crops
Parajuli et al. (2018)	LCA	Attributional	S1-GBR, EPD, ILCD	Cradle to the grave	Production of Cereals, grasses, livestock, fiber products (silage and press cake)
Pergola et al. (2018)	LCA + LCC	Attributional	GWP100, EA	Cradle to the grave	Livestock-fruitculture
Pergola et al. (2020)	LCA + LCC	Attributional	CML baseline 2001, GWP, ODP	Cradle to the grave	Horticulture
Persiani et al. (2021)	LCA + LCC	Attributional	CarbOnFarm Life +ENV/IT 000719, GWP	Cradle to the grave	Livestock (cow and buffalo), horticulture, fruit growing
Roselli et al. (2020)	LCSA	Attributional	IMPACT2002+, Eco-indicator, CML e IPCC	Crib at the gate	Grape production
Salomone et al. (2017)	LCA	Attributional	IPCC 2007 GWP 100a, CML 2 de 2000, UE	Crib at the gate	Production of Hermetia illucens

Table 2. Continued...

Paper	Technique (LCSA, LCA, LCC, S-LCA)	Approaches	Impact assessment method	LCSA scope	Application area (field of study)
Salwa et al. (2020)	LCSA	Attributional	ReCiPe Endpoint	Cradle to the grave	Food processing
Sanyé-Mengual et al. (2017)	LCSA	Attributional	SIG, IPPC 2007, ReCiPe	Cradle to the farm	Urban gardening on rooftops
Sanyé-Mengual et al. (2018)	LCSA	Attributional	ReCiPe	Cradle for fork	Horticulture
Schade et al. (2020)	LCSA	Attributional	IPCC 2013, GWP 100a, CML-IA, pre-consultants, LCI	Cradle for storage	Cultivation of microalgae and fish
Schade & Meier (2020)	LCSA	Attributional	IPPC 2013, GWP 100a, CML-IA, LCI	Cradle for storage	Cultivation of microalgae
Slorach et al. (2020)	LCA + LCC	Attributional	ReCiPe, GWB, PED	Cradle to the grave	Household food waste
Smetana et al. (2017)	LCA	Attributional	ReCiPe V1.08 e IMPACT 2002+	Cradle for processing door	Cultivation of microalgae
Smetana et al. (2019)	LCSA	Attributional	IMPACT2002 World + ReCiPe	Crib at the gate	Production of insects for feed and food
Sonesson et al. (2017)	LCA	Attributional	GWP, IPCC	Production for table	Diet foods
Stillitano et al. (2017)	LCC	Attributional	IPCC	Cradle for processing door	Fig production
Sun et al. (2019)	LCSA	Attributional	CML	Cradle to the grave	Food processing
Svanes & Johnsen (2019)	LCSA	Attributional	IPCC2006	Cradle to the grave	Production of apples, plums, and cherries
Tong et al. (2018)	LCSA	Attributional	CML2001	Table to the grave	Food waste from cafeterias
Tricase et al. (2018)	LCSA	Attributional	Impact 2002+	Cradle at the farm gate	Barley production
Ulmer et al. (2020)	LCA	Attributional	GWP, IMPACT 2002+	Cradle for processing door	Bumblebee Creation
Verduna et al. (2020)	LCSA	Attributional	ReCiPe	Cradle to retail	Milk production
Vinci and Rapa (2019)	LCA	Attributional	Impact 2002	Crib at the gate	Hydroponic cultivation
Warshay et al. (2017)	LCA	Attributional	RSB	Crib at the gate	Aquaculture
Winans et al. (2020)	LCSA	Attributional	Eco-Indicador 99	Cradle at the farm gate	Agricultural farms
Wohner et al. (2020)	LCA + LCC	Attributional	PEF	Gate to the grave	Tomato ketchup production
Yang & Campbell (2017)	LCA	Attributional	IO-LCA, ALCA	Crib at the gate	Horticulture
Yeo et al. (2019)	LCA	Attributional	CED, EROY, ReCiPe 1.02	Gate to the grave	Food waste
Yuan et al. (2018)	LCSA	Attributional	Impact 2002+, Eco-Indicador 99, CML 2001	Cradle for processing door	Bioenergy production from rice, corn, and sugar cane
Zhang et al. (2020)	LCA	Replacement	ReCiPe 2016	Cradle for processing door	Food waste
Alanya-Rosenbaum et al. (2018)	LCA	Attributional	IPCC - Global Warming (GWP100)	Cradle to the grave	Briquetting of post-harvest forest residues and dry sawmill residues
Alam et al. (2019)	LCA	Attributional	IPCC	Production for farm	Wheat production
Chen & Holden (2018)	LCSA	Attributional	IPCC	Cradle at the farm gate	Dairy farm
De Luca et al. (2018)	LCSA	Attributional	IPCC 2013, CML-Baseline, ReCiPe	Crib at the gate	Olive tree production
Gaspar et al. (2018)	LCA	Attributional	CED	Cradle for production	Fruit production
Krishnan et al. (2020)	LCA	Attributional	CML-IA	Cultivation for distribution	Mango food supply chain
Kuhn et al. (2018)	LCA	Attributional	ReCiPe v.1.08	Production for the grave	Agriculture
Longo et al. (2017)	LCA	Attributional	ILCD 2011, CED	Cradle to the grave	Organic and conventional apple supply chain
Rosa et al. (2017)	LCA	System Expansion	ReCiPe	Cradle to plate	Fresh and frozen chestnut
Schüpbach et al. (2020)	LCSA	Attributional	Agregated diversity indicator	Farm to the grave	Agricultural farms

Table 2 reveals that the majority of papers utilized techniques associated with LCA (95.7%), in contrast to LCC and S-LCA. To improve the quantification of the environmental impacts of products, processes, and services, some studies highlight the life cycle inventory–systematic compilation and quantification of inputs and outputs of materials, energy, and waste associated with a product or process throughout its life cycle (i.e., Alam et al., 2019; Cacace et al., 2020; Nindhia et al., 2021; Zhang et al., 2020), in which most studies deal with production on farms, such as apples, plums, hydroponics, horticulture, microalgae. Regarding the cost of life added to the products, which involves the acquisition, operation, and maintenance of the elements were found in 29.6% of the studies which used the LCC tool (i.e., Konstantas et al., 2019; Pergola et al., 2018, 2020; Persiani et al., 2021; Verduna et al., 2020).

Some authors have developed a complete application of the LCSA tool to identify social networks' environmental and economic impacts. Among these, the following stand out: Chen & Holden (2018) evaluated the impacts of the dairy farm; De Luca et al. (2018) evaluated the impacts of the olive grove; and Schüpbach et al. (2020) evaluated the impacts of some agricultural farms. Regarding the approach used, 95.8% of the studies used the attributional approach, with the allocation of associated impacts, while only 2.8% used the system expansion approach and 1.4% used the replacement approach.

Regarding the impact assessment methods used by the sample of this study, the Intergovernmental Panel for Climate Change (IPCC) (i.e., Bergström et al., 2020; Edwards et al., 2018a, b; Roselli et al., 2020) was the most used method. Generally, this method is used to assess the Global Warming Potential (GWP) with a horizon of 20, 100, or 500 years, where the higher the value of the GWP, the more significant the impact. On the other hand, several authors used the CED (Cumulative Energy Demand) method to assess the impacts related to the scarcity of energy resources (Gaspar et al., 2018; Longo et al., 2017; Yeo et al., 2019). Another method widely used in the studied sectors is the CML (Edwards et al., 2018a, b; Elginoz et al., 2020; Pergola et al., 2020), generally used to evaluate the effects on the depletion of fossil fuel and materials; global warming; ozone layer; human health; health of freshwater, marine, and terrestrial ecosystems; atmospheric pollution; acid rain; and eutrophication.

Other impact assessment methods were used on a smaller scale, for example, ReCiPe (RIVM, CML and Pre Consultants) (i.e., Benis & Ferrao, 2017; Cancino-Espinoza et al., 2018; Cacace et al., 2020; Zhang et al., 2020), Aggregate Diversity Indicator (Schüpbach et al., 2020) and ILCD (International Reference Life Cycle Data System) 2011 (i.e., Albizzati et al., 2021; Castellani et al., 2017; Brancoli et al., 2017; Cristóbal et al., 2016). It is noted that a wide variety of methods were used, considering that the areas of agriculture and food processing are broad and with a large number of processes to be investigated. Regarding the area of application, 47.9% present studies related to the food processing sector and 52.1% related to the agricultural sector, revealing a balanced interest between these sectors.

Table 2 demonstrates that researchers use different combinations to apply the LCSA, given that there is still no consensus on how such assessments can be more effective, reflect correct results, and be used in a managerial. This occurs even in more consolidated techniques in the literature, such as LCC. Degieter et al. (2022) highlight that one of the main criticalities in integrating the LCC into the LCSA is mainly due to the lack of a standard definition of the cost categories to be included in the study. In their review, the authors found that all cost categories were critical for LCSA results in agri-food products. For this reason, there was a prevalence in the studies that investigated the integration of LCC with multicriteria methods. According to De Luca et al. (2017), the integration of LCSA with MCDA can be an effective way to reduce subjectivity in LCSA studies, mainly from the consideration of the points of view of different stakeholders, given the complexity of assessments in the agri-food sector. This finding is corroborated by the results of Degieter et al. (2022), which highlight the difficulties still encountered in delimiting the scope of evaluations in this context.

In addition, Tragnone et al. (2022) argue that the lack of data and subjectivity in delimiting system boundaries, including the absence of well-defined criteria for choosing indicators, impact the reliability of LSCA results in the agri-food sector. Furthermore, according to the authors, studies in this field of research should be more attentive to the relationship between products and territories, with the integration of territorial life cycle assessment approaches, which is still incipient in the literature.

4.3. Finding research opportunities

Regarding future research proposed in the selected studies related to modeling scenarios in the agricultural sector, it was possible to observe the following: apply the LCA in alternative solutions of heat quantities to evaluate the potential for emission of greenhouse gases (Alanya-Rosenbaum et al., 2018); improving fuel and fertilizer use in primary and energy production (Rosa et al., 2017); to study the potential of changes in energy sources in microalgae production (Smetana et al., 2017); finding the best combination of inputs in the hydroponic production process (Vinci & Rapa, 2019), and consider the technology used in the cultivation phase when moving from current conventional food production systems to a locally produced food scenario (Vinci & Rapa, 2019; Sanyé-Mengual et al., 2018; Sanyé-Mengual et al., 2017).

Table 3. Research Agenda for future studies.

Sector	Questions
Agricultural	How can LCA in random samples provide greater precision on the GHG reduction potential of biogas?
	What are the important indicators to consider while developing an LCSA for agriculture processes?
	How can LCA support agricultural production based on waste management?
	How can the assessment of social activities by S-LCA support the minimization of environmental and economic damage to the agricultural sector?
Agri-Food Chain	What are the best practices for reducing poverty and using agri-food surpluses for sustainable development?
	What are the bets tools to evaluate sensitivity analysis on SLCA for the agri-food sector?
	How can multi-criteria methods support the creation of guidelines for an adequate choice of Functional Units for the agri-food sector?
	How can SLCA support on sustainability studies for agri-food land use?
Food Processing	What type of method is most efficient for assess impacts in the food systems?
	How to implement accurate primary data on machinery used and its energy consumption in LCSA in food processing industries?

Furthermore, in the food processing sector, some possible improvements were proposed by the sampled authors, such as a comparative study of the non-renewable and renewable energy impacts evaluation (Gaspar et al., 2018; Parajuli et al., 2018); assess the amount of manure transported, as well as the change in transport distances (Kuhn et al., 2018; Salomone et al., 2017); explore a choice for more sustainable food development (Sonesson et al., 2017), and use multi-criteria methods to classify products and sectors in terms of their eco-efficiency (Konstantas et al., 2019).

Some authors have proposed improvements for agriculture regarding the life cycles inventory, such as alternative weed control techniques, alternative herbicides, and other mechanical weeding operations (De Luca et al., 2018; Pergola et al., 2020; Sanyé-Mengual et al., 2018), and standardizing procedures for developing an LCA inventory (Schade et al., 2020; Schade & Meier, 2020; Wohner et al., 2020). At the same time, concerning the food processing sector, they suggested improving the generalization of the results of the studied object globally, with more significant data collection (Krishnan et al., 2020). As for the LCC assessment in the agricultural sector, it was suggested to include the economic aspect together with the environmental one in the creation of a recycling assessment tool (Lam et al., 2018); and to develop, within the farms, more sustainable alternatives from the application of the LCC (Roselli et al., 2020). In the food processing sector, some suggestions regarding the LCC were: formulating an assessment tool for the feasibility of developing a composting facility (Salwa et al., 2020), using technologies capable of differentiating shelf life, and considering the impact of wasted food (Cacace et al., 2020).

Finally, according to the development of SLCA, the proposals are to develop quantitative social indicators related to the evaluated indicators, which could be achieved by combining SLCA with input-output methods (Chen & Holden, 2018), investigating the relationship between amino acid use and microalgae production (Schade et al., 2020), and estimate baseline benefits for material management on farms (Winans et al., 2020). Given the above, Table 3 presents research questions explored in future studies.

It is noted that the selected articles include few studies concerning the S-LCA tool, which deals with the social bias of the Life Cycle, resulting in the need to carry out studies that address the three levels of the LCSA in the agri-food sector. Therefore, this gap constitutes an opportunity for future studies, which can contribute to poverty reduction and the better use of surplus food in search of sustainable development.

5. Conclusion

This study aimed to identify trends in applying the LCSA technique in the agricultural and food processing sectors, considering the Environmental, Economic, and Social Perspectives. The study was conducted through a systematic literature review followed by bibliometric analysis, content analysis, and findings of opportunities for future research. The systematic review revealed 71 relevant articles on the topic of interest, LCSA applications.

The bibliometric analysis carried out with the support of the Bibliometrix package, revealed that the areas studied have two clusters that separate studies between the food processing sector and the agricultural sector, representing 47.9% and 52.1% of the studies, respectively. The factorial analysis derives two keyword classifications; one represents data on LCM methods, the main themes studied, and the other focuses on empirical applications. Of these studies, most are present in high-impact journals with many citations, of which 95.7% prevail using the LCA technique. As for the allocation approach used, the authors chose the attributional approach, representing 49.3% of the studies concerning the impact assessment methods: IPCC, GWP, CED, and CML.

The content analysis, in turn, revealed that most studies apply the environmental assessment of the life cycle, coupling in some studies with the economic and social view, as well as mainly using an attributional approach with the scope ranging from the cradle to the grave with area terms. Thus, agricultural and food processing applications provide gaps and trends for developing studies in these sectors. Another critical factor in the plethora of studies to be developed is the evaluation of scenarios, considering relevant variables in different perspectives and applications. This proposal contributes to comparative studies and supports the decision-making process.

The main limitation of this study is the difficulty of evaluating empirically the adoption of LCSA in the agricultural and food processing sectors. This study presents a triad of contributions, as theoretical, evaluated 71 papers related to LCSA applications in the main sectors related to agri-food sectors. As for methodologies, this study employs systematic literature review and bibliometric analysis using advanced protocols and software. Finally, as empirical contributions, the total studied sample is empirical, so the evaluation presents practical studies that support decision-makers in the agri-food sector.

The survey of future research opportunities indicates that authors develop LCSA in these sectors with different materials that serve as inputs to the processes, varying the energy and transport used in natural and hypothetical scenarios. In addition to evaluating the uncertainties of the data used in the modeling. These studies can be compared and developed in different regions to assess changes in the impacts generated in studies that assess the seasonality of products and processes. Finally, when studying LCSA in the agricultural and food processing sectors, inventories should be developed for the processes in the country of origin.

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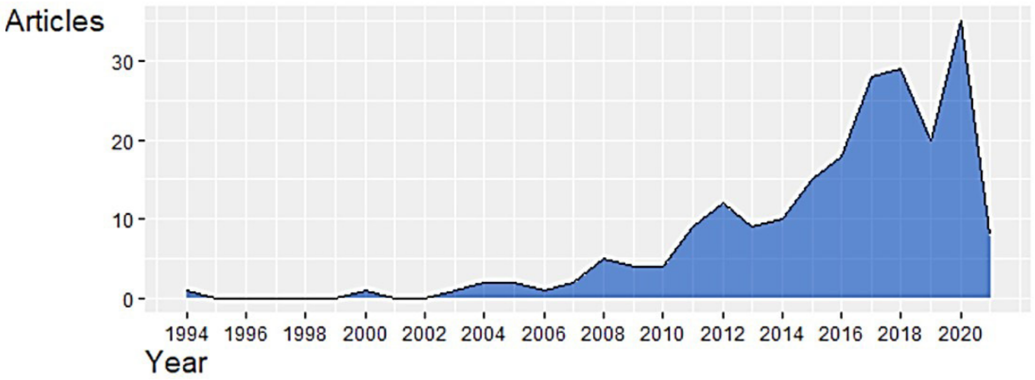
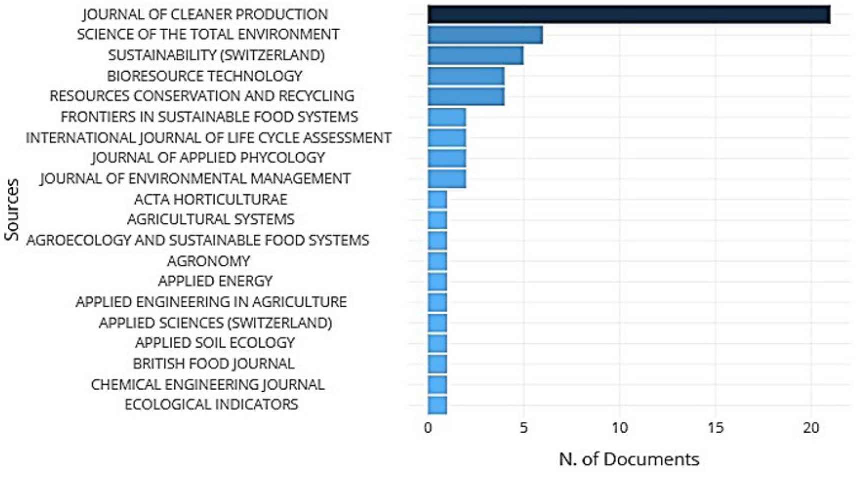
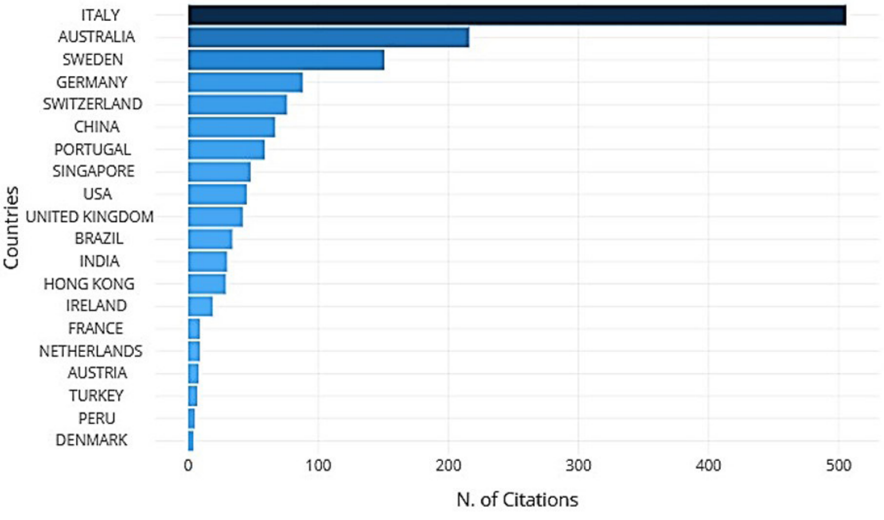
Appendix A. Annual Scientific Production.



Appendix B. Number of articles per journal.



Appendix C. Most cited countries.



Appendix D. Author production over time.