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AGRICULTURAL LIFE CYCLE ASSESSMENT: A SYSTEM-WIDE BIBLIOMETRIC RESEARCH

Purpose. *This paper aims to give a system-wide overview of agricultural life cycle assessment (LCA), based on the understanding of agriculture as a complex providing humanity with food, energy and other vital resources and considering all forms of sector's influence: environmental, social, and economic. This review is intended to outline the temporal and geographical spread of agricultural LCA research, the main aspects studied with LCA in agriculture, and relevant scientific themes via bibliometric analysis and an overview of high-quality scientific publications in this field.*

Methodology / approach. *This study used traditional bibliometric research techniques: performance analysis, scientific mapping, and network analysis. Bibliometric analysis was conducted through the Bibliometrix R package in the RStudio and its extension – Biblioshiny. The bibliographic collection covers 259 academic English-language articles indexed in Scopus for 1999–2022.*

Results. *The study identifies a significant growth in a number of agricultural LCA publications, a tendency of current LCA research to continue and complement earlier research findings, and to accentuate environmental aspects of agricultural activity. Developed countries lead this field of research in terms of productivity and impact. However, LCA studies are geographically concentrated, and collaboration between developed and developing countries is weak. The following issues shape the agri-LCA research structure: greenhouse gas (GHG) emissions analysis; LCA of various impacts of agriculture; challenges of agriculture environmental impacts measuring; LCA usage to ensure agriculture sustainability; agri-LCA methodology. Emphasis on GHG emissions in agri-LCA could lead to biased decisions promoting climate-resilient agriculture but neglecting other impacts and dimensions of the sector's sustainability.*

Originality / scientific novelty. *It was found that the rapid development of the field of research featured a certain stability, continuity, and historical relationship between the issues studied. Research transform from a highly specialised topic into a broader one by the scope of publishing sources but are highly geographically concentrated and not equally distributed even within the European Union. As far as is known, these results have not been previously reported.*

Practical value / implications. *The identified "closedness" of the research community leads to weak scientific progress. Sharing knowledge and involving a broader set of stakeholders to promote LCA application in agriculture globally must be a priority of scholars and policymakers.*

Key words: *agriculture, life cycle assessment, life cycle costing, social life cycle assessment, sustainability, Biblioshiny.*

1. INTRODUCTION

Agriculture is the most critical industry for human development: it provides food and fodder, energy and raw materials for other sectors. According to the World Bank

[1], agriculture employs one in four workers in the world (27 %) and generates about 4 % of global GDP annually. Along with that, agriculture withdraws more than 70 % of total freshwater, generates more than 12 % of total GHG emissions [2], occupies more than a third part of the terrestrial world (arable land amount to 36.5 % of total land area) [1], and directly affects the well-being of 43 % of the world's population living in rural areas [3]. The above-listed effects, being already well known, highlight not only the need for sustainable industry transformation – that is not discussed anymore – but the sector's complexity and multifaceted impacts that need to be taken into account when making decisions about concrete steps towards agriculture sustainability. Life Cycle Assessment (LCA) is promoted as a leading approach to inform these decisions [4–8]. Elaborating sustainable strategies for agriculture development requires finding trade-offs between food production and soil cultivation for energy, fibre, and other raw materials production based on appropriate LCA results [9–11]. Thus, the expansion, relevance, and comprehensiveness of agri-LCA studies determine the success and speed of sustainable transformations. This necessitates an investigation of the current knowledge and research progress in agricultural LCA. Insights into accumulated knowledge and knowledge gaps could inform policy decisions [12–14] and guide further research efforts.

This paper aims to give a system-wide overview of agricultural LCA, based on the understanding agriculture as a complex providing humanity with food, energy and other vital resources and considering all forms of sector's influence: environmental, social, and economic. The following research questions guide this study: What is the general trend in agri-LCA research activity? What are the temporal and geographical patterns of agri-LCA research? What are the main areas and aspects covered, and could they provide valuable insights into elaborating comprehensive sustainable agricultural policies?

2. LITERATURE REVIEW

Current research reveal the relevance of LCA studies in agriculture and related fields, however being limited mainly by specific products or sectors: milk [15], olive oil [16; 17], plant-based protein-rich foodstuffs [18], product groups [19; 20], and food-related supply chains (catering [21], food waste [22; 23], food packaging [24], food supply chains [25], bioeconomy solutions [26]).

As the methodology of LCA is further developing (going beyond traditional environmental assessment towards comprehensive sustainability assessment), involvement of social and economic issues via Social LCA (SLCA), Life Cycle Costing (LCC), an exploration of comprehensiveness and implementation of such methods in agriculture gain importance. Some reviews generalise the experience of LCC application in agriculture [6] and food waste chains [7]. Though, it's not enough to understand the expansion and comprehensiveness of LCA research in agriculture, given the sector's multifunctionality and variety of impacts.

Only few publications [27–31] reveal the broader context of LCA application in agriculture. Fan et al. [27] systematically reviewed publications indexed in the ISI Web of Knowledge concerning the LCA experience in crop production (limiting the collection by studies using more than one LCA indicator). They emphasised the need for further improvement of the LCA methodology: allocation procedure, functional unit selection, and LCA integration with other decision-making tools. Alhashim et al. [28] apply a similar approach – narrowing the collection by crop production and several impact categories – but consider only LCA studies with GHG and/or ecotoxicity categories, thus covering rather LCA of the impact of agricultural production on climate change and ecotoxicity, but not the full LCA's potential for sustainable agriculture transformation. Gava et al. [29] – reviewing academic publications indexed in Scopus and Web of Science in January 2019 with the keywords "life cycle assessment" and "agriculture" or "food" – found the growing attention to LCA application to justify waste circularisation and corresponding strategies, and the lack of systemic LCA practices in agriculture. The authors limited the collection to agricultural economics and policy subject areas, so the results do not reveal LCA's system-wide agricultural implementation. Ruviaro et al. [30] made a systematic literature review on LCA application in agriculture globally and in Brazil, which is the broadest. Scholars examined publications of government institutions and scientific literature for 2001–2011 (86 documents) and found an increase in the number of publications since 2007 (authors explained this as a response to public demand for greater transparency and monitoring of environmental impacts due to global agreements such as the Kyoto Protocol), a prevalence of LCA use to compare different production systems (organic and conventional, extensive and intensive, small and large, traditional and developed), evidence of LCA and other methods integration to obtain better results in terms of agriculture environmental impact assessment. Assessing the spread of LCA application among agricultural sectors, authors attributed the dominance of LCA in livestock production (58 %) compared to crop (36 %) and other agricultural products (6 %) to the ascendancy of EU-related research, where livestock production is more common. Like narrower research, this review [30] indicates the heterogeneity of LCA procedures and results, the incomparability of LCA outcomes, and the inability to extend conclusions to other product systems. Later, Claudino & Talamini [31] conducted a similar by-context bibliometric review of research devoted to the implementation of LCA practices in agribusiness; however, limiting only to the Brazilian experience. To the best of our knowledge, there is no recent review with the broader coverage of LCA application in agriculture globally, including environmental but also social and economic issues.

3. METHODOLOGY

This study covers publications indexed in Scopus because this database contains more unique records than the Web of Science [32; 33]. The following search query was applied for titles-abstracts-keywords: "agr*" within three words of "life cycle analysis" or "life cycle assessment" or "life cycle cost*" or "life cycle impact" or "*lca" or "*lcia" or "lcc" (as of October 3, 2022). The phrase choice to form the sample was made because of the complexity of agriculture (and possible lexical forms) and the diversity of agriculture impacts covered by different LCA types and procedures. The limitation of the words' proximity allowed for avoiding the so-called "informational noise", i.e. including little related to agriculture LCA research. Through "agr*" wording, it was aimed to cover all possible synonyms: agrarian, agriculture, agricultural, agribusiness, agri-food, and others similar. Different variants of LCA type naming were added to the search query, allowing to cover the social context (for example, in the term "SLCA" via "*lca"). Initially, the search result contained 508 documents. The sample was limited by the type of sources and language – only English-language academic journals – resulting in 367 publications. The primary screening of the sample (titles and abstracts only related to agriculture and agri-food issues) was made to exclude irrelevant publications. In this step, research related to "latent class analysis" in medicine, land cover analysis or change (included due to "LCA" and "lcc" abbreviation), building and construction issues, packaging, and education for nutrition were excluded. Reviews (bibliometric, systematic) were also excluded to avoid any bias caused by more frequent words in the reviews. The final sample covered 259 documents (supporting data are listed in [34]).

The research scope determines the methods and techniques applied. Bibliometric analysis, based on quantitative methods, allows, in contrast to the systematic review, for both avoiding the bias caused by the subjective interpretation and studying a significant volume of literature to generalise the research field [35–37]. This study used traditional bibliometric research techniques: performance analysis, scientific mapping, and network analysis. Bibliometric analysis was conducted through the Bibliometrix R package in the RStudio [38; 39] and its extension – Biblioshiny. The latter allows for a full-fledged analysis of the bibliographic collection, revealing not only scientometric data but also social, institutional, intellectual structures and conceptual insights [40].

The screening of the research sample (keywords) witnessed many synonyms and similar grammatical forms for the main lexical constructions. Keywords data were harmonised to address this issue and provide better exposure to key concepts. In particular, the term "life cycle assessment" was used to replace the following phrases used separately, i.e. excluding words like "agricultural LCA" and similar: "Life cycle assessment" (used 78 times), "lca" (37), "life cycle assessment (lca)" (13), "lcalife cycle assessment" (1), "life cycle assessment" (1), "life -cycle assessment (lca)" (2), "lifecycle assessment (lca)" (2). A similar operation was applied to all grammatical forms and abbreviations of the phrases "Life cycle impact assessment", "Life cycle inventory", "life cycle costing", "global warming potential", "greenhouse gas", and "carbon footprint". The appropriate singular form replaced some plural terms: system, impact, biofuel, emission, investment, change, method, crop, product, unit, and pesticide. Then duplicate keywords in the same document were removed (for example, LCA and life cycle assessment).

4. RESULTS

4.1. Research dynamics, geographic and institutional patterns. Table 1 summarises the main parameters of the collection, allowing for performance analysis.

Almost one thousand scholars are engaged in research on LCA application in agriculture, mainly within a research team of five members on average. The share of single-authored publications amounts to only 4.6 % of the total collection: only one in ninety authors publish individually. The average number of citations is 4.398 per publication annually, and it takes over six years for a publication to be cited.

Table 1

Descriptive statistics for bibliographic collection

Section	Description	Value
Main information about data	Timespan	1999–2022
	Sources (Journals)	88
	Documents	259
	Average years from publication	6.03
	Average citations per documents	35.42
	Average citations per year per document	4.398
	References	13799
Document contents	Keywords plus (ID)	2030
	Author keywords (DE)	872
	Author keywords (DE) harmonised	830
Authors	Authors	963
	Author appearances	1153
	Authors of single-authored documents	11
	Authors of multi-authored documents	952
Authors collaboration	Single-authored documents	12
	Documents per Author	0.269
	Authors per Document	3.72
	Co-Authors per Documents	4.45
	Collaboration Index	3.85

Source: authors' development via Biblioshiny.

The first publication in the sample dates to 1999; in 1999–2002, there was a growing interest concerning the LCA in agriculture, followed by the recession: no studies published in 2003–2004 were found in Scopus (Figure 1). The presence of relevant publications every year since 2005 illustrates stability and relevance the research field was getting. The publication activity dynamics are wave-like, with an average annual growth rate of 12.1 %. Despite the periods of recession (2003–2004, 2008, 2016, 2019), the number of publications has grown exponentially and doubled in 2021 compared to 2015.

Even though there was a decline in the number of publications in 2008 (Figure 1), two articles published that year are among the most cited (Figure 2), having 173 total citations per article on average and 12.36 citations annually. Publications in 2000 (four articles) and 2001 (one article) also have high citation rates: 157.25 and 163 total citations per article on average. In addition to the above, 25 articles published in 2017 are also highly cited annually: 53.64 citations per article on average and 10.73 per article per year. This evidences the formation of a particular set of relevant research topics in 2000–2001, 2008, and 2017.

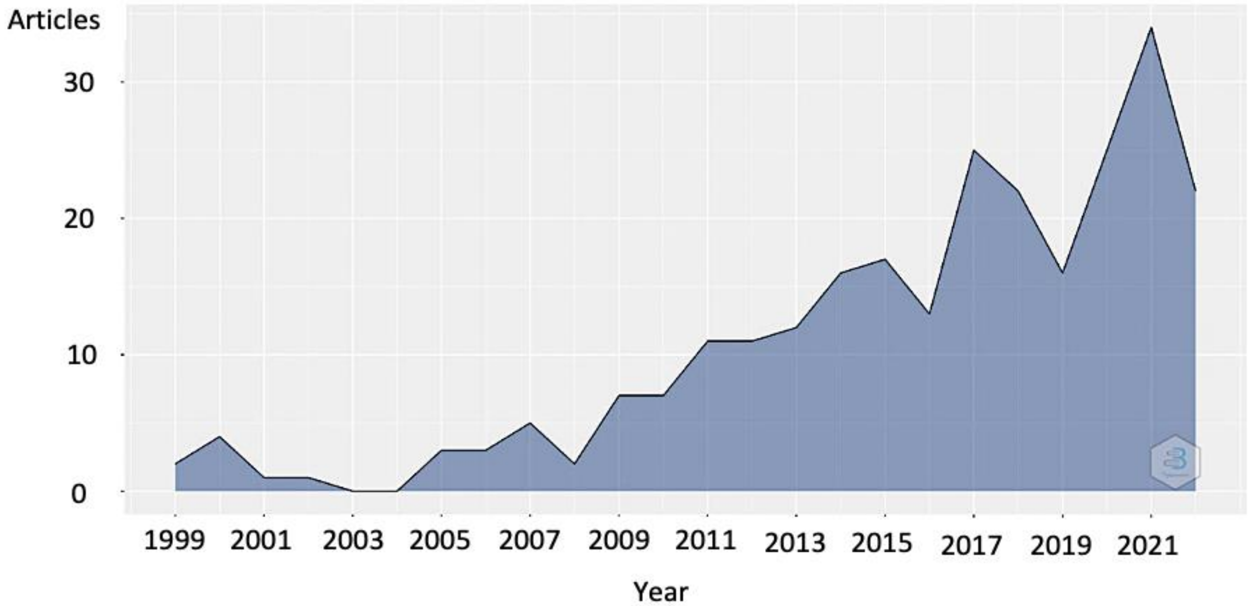


Figure 1. Historical development of the research field: annual scientific production

Source: authors' development via Biblioshiny.

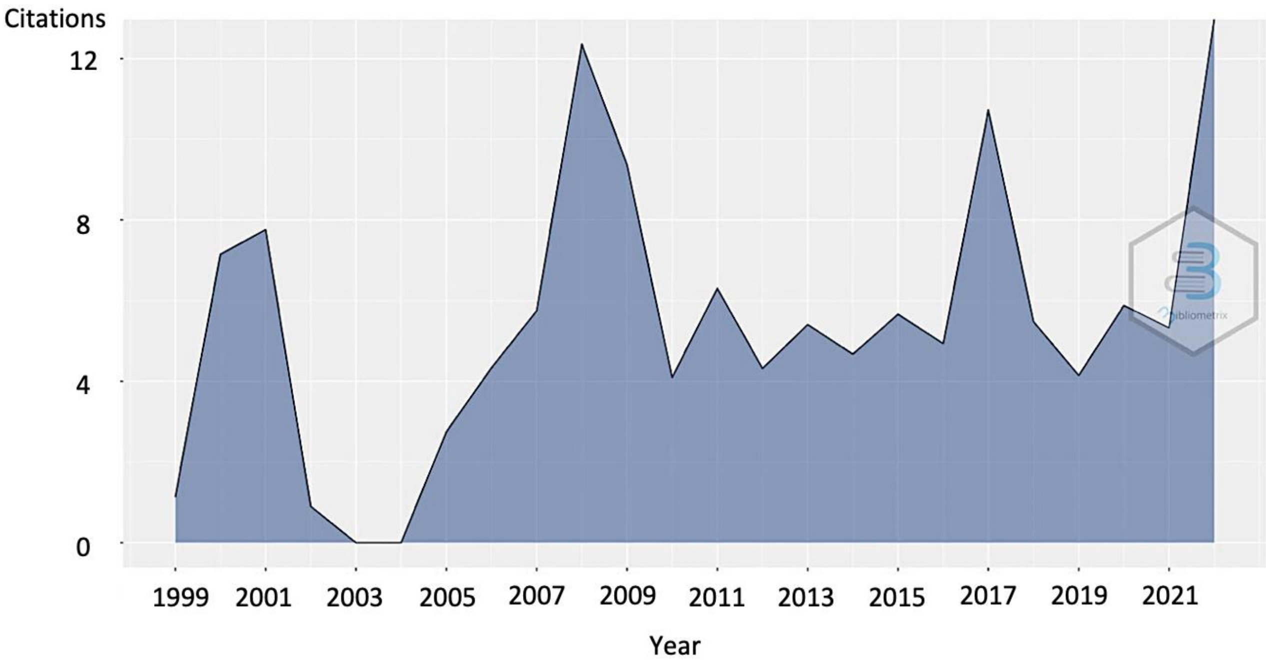


Figure 2. Historical development of research field: average article citation per year

Source: authors' development via Biblioshiny.

Documents from the collection represent different fields of knowledge according to the Scopus classification (Figure 3), with a predominance of studies in the Environmental Science area constituting more than a third of the sample. Research in Energy, Engineering, Agriculture and Biological Sciences, Business, Management and Accounting amount to a little more than 50 % of the sample, with a predominance of the Energy area.

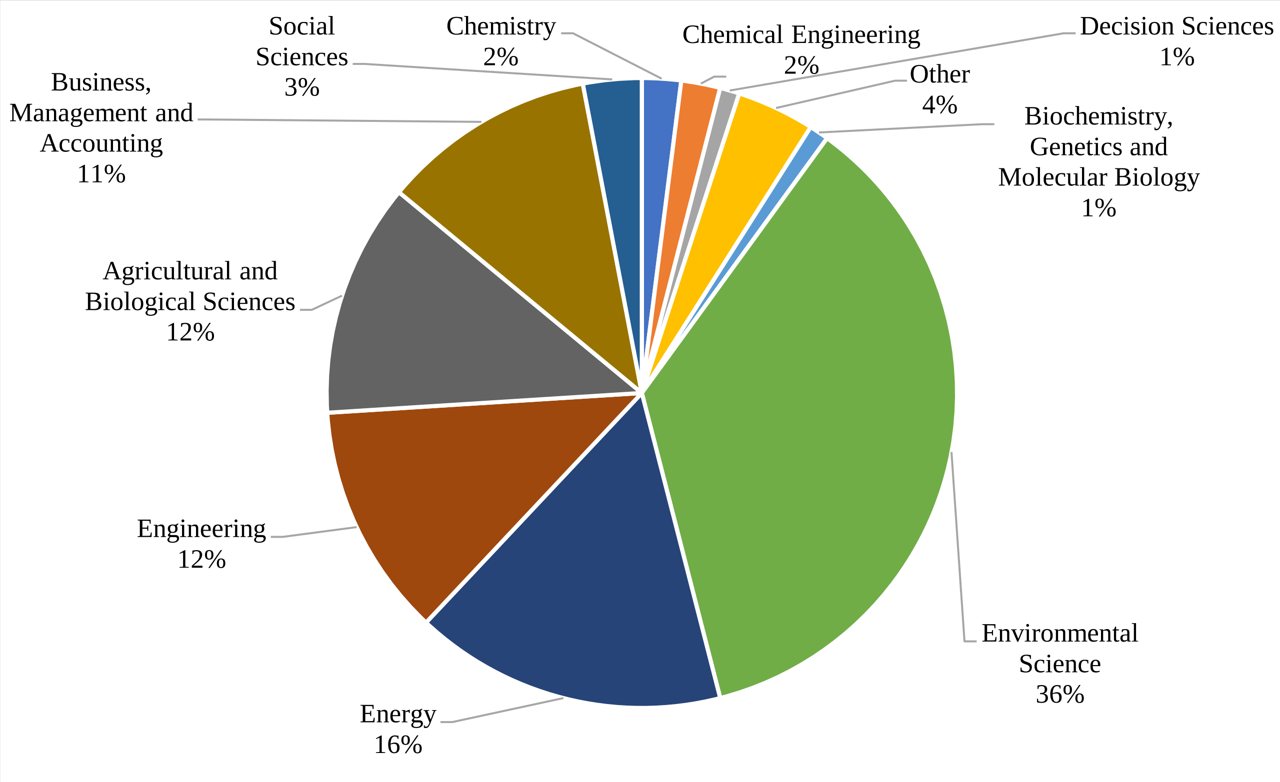


Figure 3. Scopus subject areas

Source: Scopus data.

The Journal of Cleaner Production and the International Journal of Life Cycle Assessment are the leading platforms for publishing research results on LCA application in agriculture (Figure 4): a little more than 40 % (41.31 %) of the documents from the analysed collection were published in these journals. The Journal of Cleaner Production holds leadership in annual publications; the International Journal of Life Cycle Assessment led only in 2009–2011 and 2019–2021.

In 1999 and 2000, the Journal of Cleaner Production and the International Journal of Life Cycle Assessment were the only journals publishing research about LCA application in agriculture. The European Journal of Agronomy has also become a platform for disseminating research results in this field since 2001 when the first relevant article was published. The first publications in Agricultural Systems appeared in 2007 (one article), in Environmental Science and Technology – in 2012 (two articles), and the Science of the Total Environment – in 2016 (two articles). Although LCA originates from the environmental management field, specialised journals – the Journal of Environmental Management and the Integrated Environmental Assessment and Management – published the first relevant publications only in 2009 and 2017, respectively. Certain neglection of the sustainability dimension of agricultural LCA is also evident: the Frontiers in Sustainable Food Systems and the Sustainability (Switzerland) have published appropriate research only recently (in 2020 and 2019, respectively). Commenting on the sources' influence, one should note that the Journal of Cleaner Production has the highest h-index (31), and the International Journal of Life Cycle Assessment indicator is 19. Other journals from the top 20 have significantly lower h-index values varying from 2 to 7. However, such journals as the Science of the Total Environment (h-index = 7), Sustainability (Switzerland) (h-index = 4), and Agronomy (h-index = 2) have the m-index value of more than 1.0, being close to the m-index of the Journal of Cleaner Production (1.33).

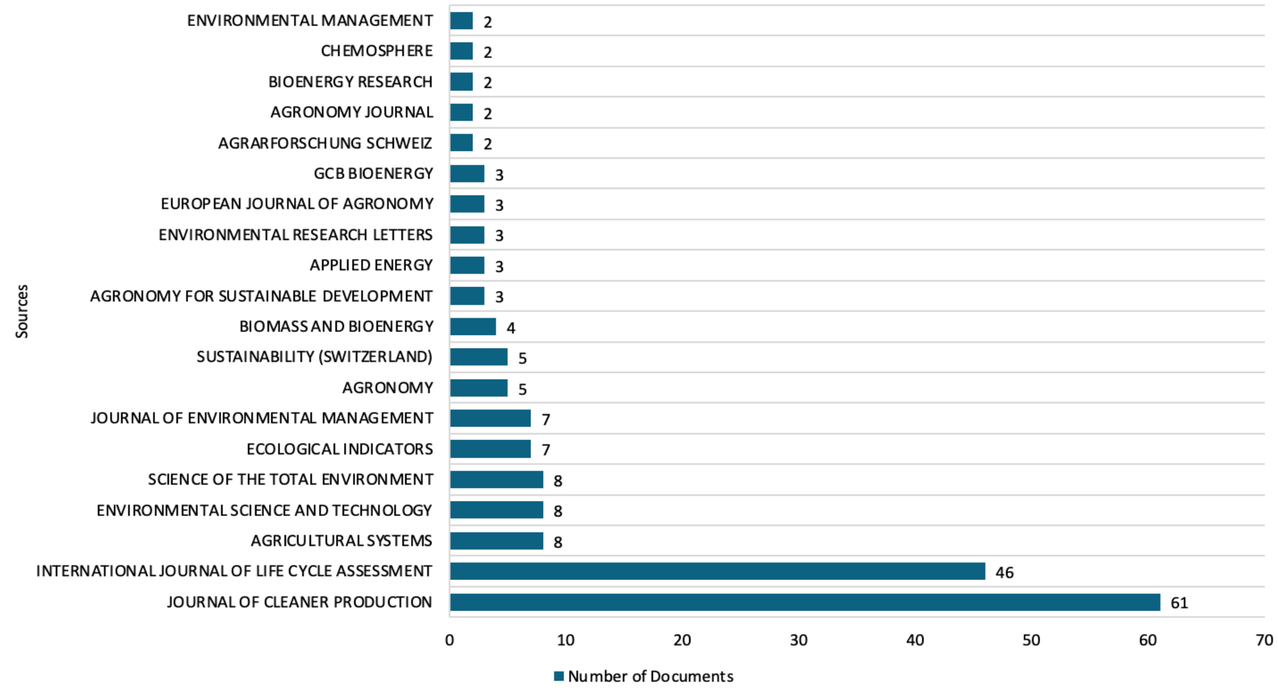


Figure 4. Most relevant sources

Source: authors' development via Biblioshiny and MS Excel.

Developed countries lead in this research field (Figure 5). The following countries constitute the top five by the number of publications: France (80 publications), the USA (77), Italy (50), Spain (46) and Switzerland (40). In addition to the listed above, only ten countries exceed the value of an average number of publications per country (13): China (37), Germany (36), the UK (29), Australia (24), Denmark (21), Belgium (20), Brazil (20), Canada (20), Japan (17), the Netherlands (15).

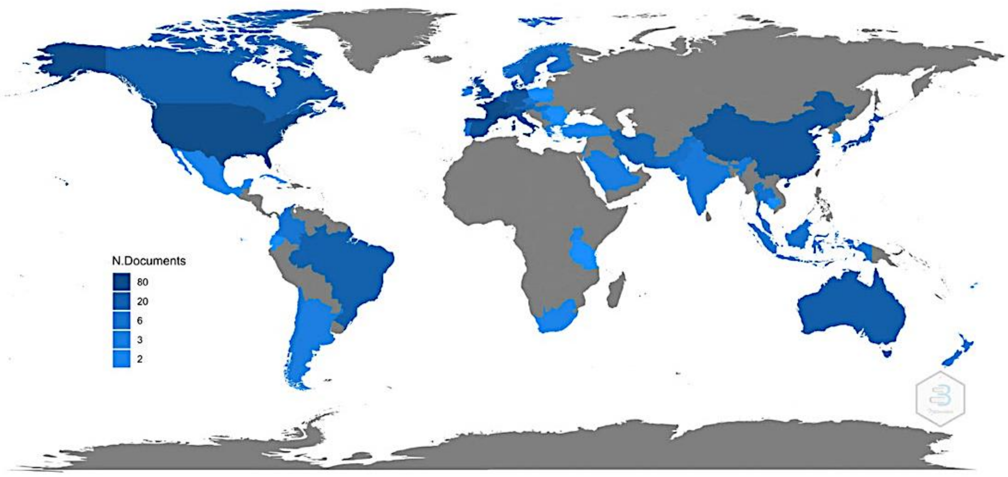


Figure 5. Country scientific production

Source: authors' development via Biblioshiny.

One should note the excessive number of publications made by scholars in the least developed countries like Pakistan (7), Indonesia (6), Malaysia (6), and Thailand (6) compared to the number of publications in some EU member states: the Czech Republic (5), Hungary (5), and others. In general, the eastern EU members demonstrate low research activity: Poland, Bulgaria, and Romania have only one publication each. Despite its role in global agriculture, the number of publications from India is also low (4).

Although only one publication in the collection was associated with Poland, this article ensured the country's leadership by the number of citations per publication (Table 2). In addition, Italy and France, leading in the number of total citations (1169 and 1041), have fewer citations per article than the top ten listed in Table 2 (44.96 and 38.56, respectively).

Table 2

The most and the least relevant countries

The most productive countries			Countries cited the least		
Country	TC*	TCpA**	Country	TC*	TCpA**
Poland	80	80	Mexico	0	0
UK	746	67.82	India	2	0.67
Norway	63	63	Chile	1	1
Denmark	425	53.13	Romania	1	1
Germany	583	53	Czech Republic	7	2.33
Switzerland	970	51.05	Indonesia	6	3
Greece	50	50	Canada	15	3.75
Australia	199	49.75	Argentina	4	4
Ireland	98	49	Fiji	4	4
USA	1201	46.19	Turkey	4	4

Note. *TC – total citations; **TCpA – total citations per article.
Source: authors' development via Biblioshiny.

The top five leading countries, measured by affiliation to the corresponding author, are somewhat different: France, Italy, the USA, Switzerland, and China (Figure 6).

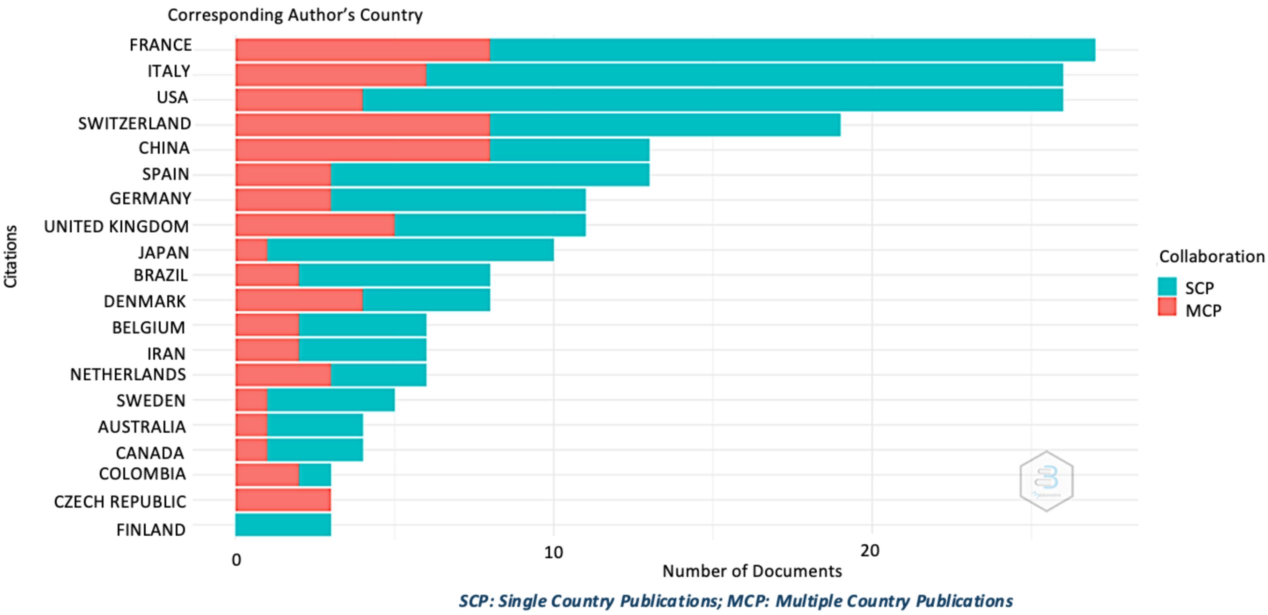


Figure 6. Collaboration among the countries

Source: authors' development via Biblioshiny.

Corresponding authors from France, Switzerland and China are leaders in the number of research conducted by an international team (eight international publications for each country), while several European countries (Finland, Portugal, Austria, Hungary, Greece, Poland, Romania), Turkey, and some least developed countries (Indonesia, Kuwait, Malaysia, Uganda) lag behind, because they have no international research at all. The Czech Republic, Luxembourg, Argentina, Chile, Fiji, Mexico, Norway, and Pakistan have the highest ratio of international collaboration (1.0).

Results of network mapping (Figure 7) indicate the closest research cooperation between developed countries (mainly European) and weak collaboration outside.

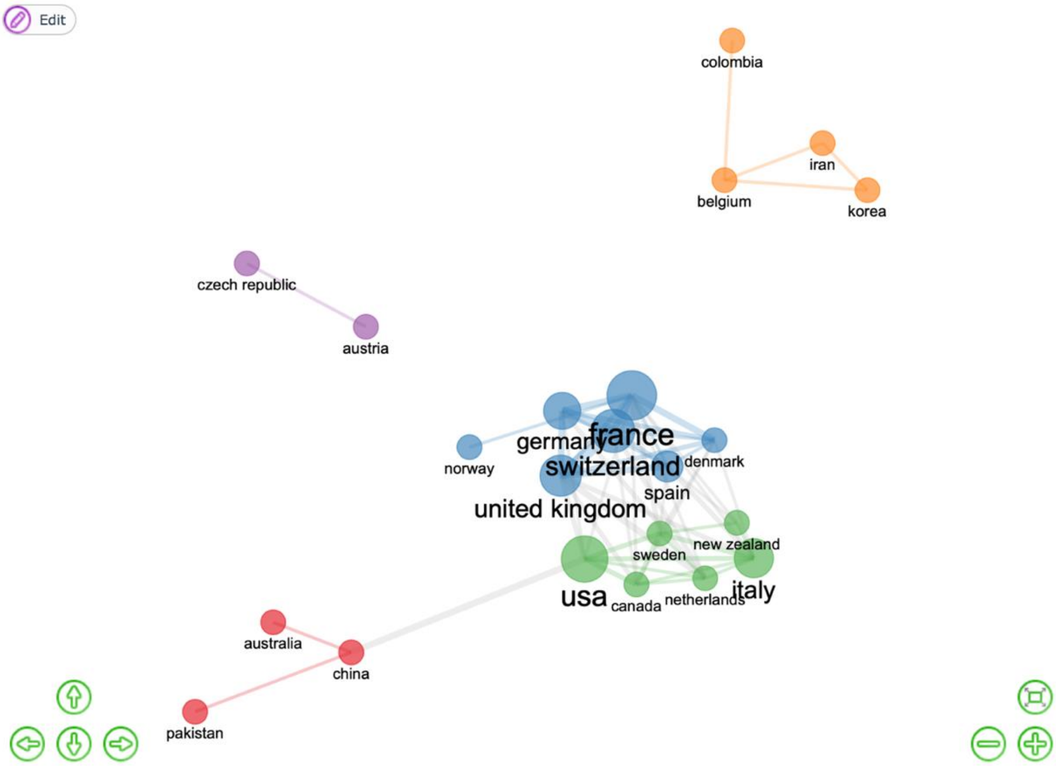


Figure 7. Collaboration network map of the countries

Source: authors' development via Biblioshiny.

Five clusters of international research cooperation were automatically detected: 1) Central European led by France, Switzerland, and the UK; 2) American-European (the USA and Italy among the leaders) closely interacting with the Central European cluster; 3) Eastern (China, Pakistan, Australia), collaborating with the American-European cluster; 4) Eastern European cluster integrating scholars from Austria and the Czech Republic; 5) Asian-European (Iran, Korea, and Belgium in cooperation with Colombia).

The collection includes documents authored by scholars affiliated with 436 institutions. The Technical University of Denmark and the University of Montpellier (France) are the most productive, with a total of 10 publications per institution (Figure 8). The Institute of Environmental Engineering (Switzerland) and the University of California (USA) have seven publications each and, together with the Colorado State University (the USA) having six publications, are among the top five the most productive institutions. The authors did not indicate affiliation in seven publications.

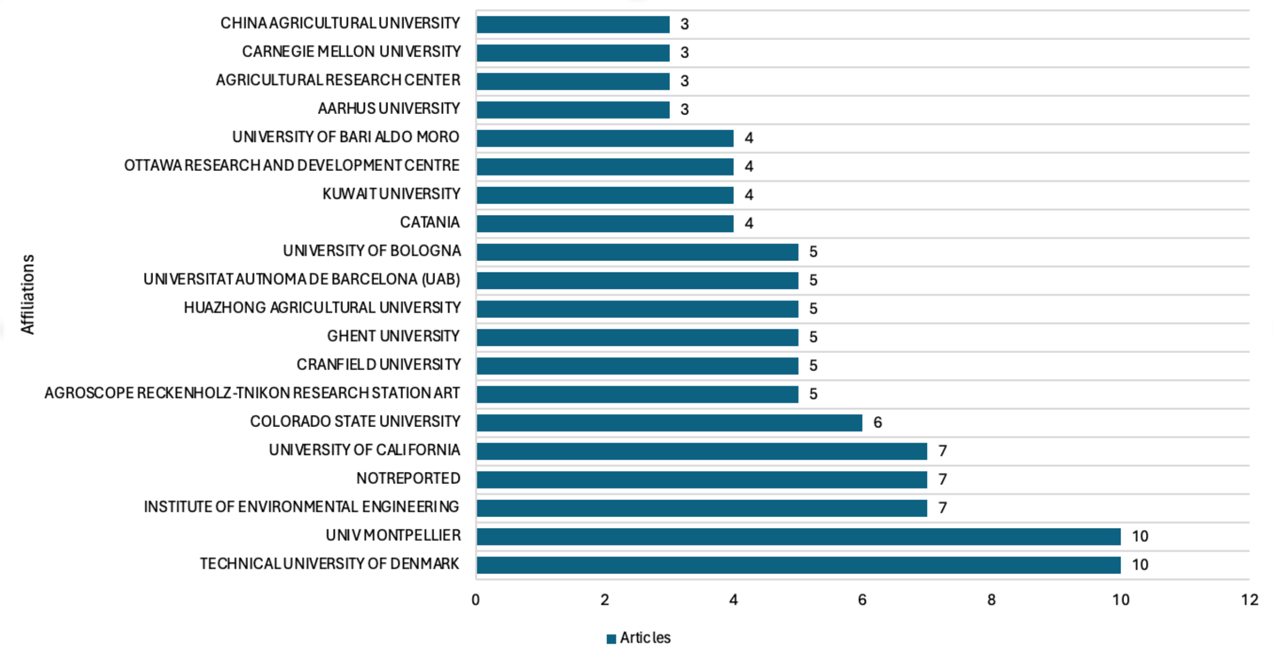


Figure 8. Most relevant affiliations by articles published

Source: authors' development via Biblioshiny and MS Excel.

The most productive scholars (by the number of documents fractionalised) are as follows: Hayashi (3.28), van der Werf (2.46), Nemecek (2.44), Gaillard (1.65), Nikkhah (1.58), Pfister (1.50), Basset-Mens (1.48), Teixeira (1.33), Brankatschk (1.20), Hansson (1.14), Antn (1.09), Finkbeiner, Blanco-Canqui, Hotta, Lindeijer, Mangmeechai (1.0 each). Other authors have less than one publication. The top five authors by the total number of publications include Nemecek (14 publications), Gaillard and van der Werf (nine each), and Basset-Mens and Hayashi (six each).

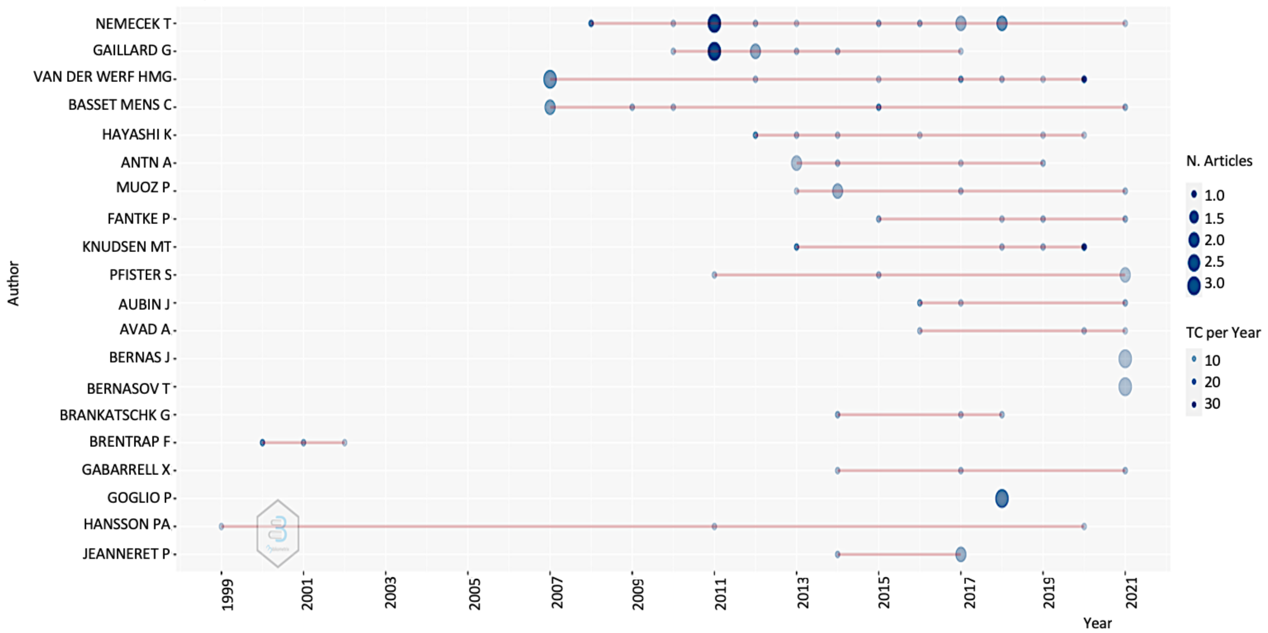
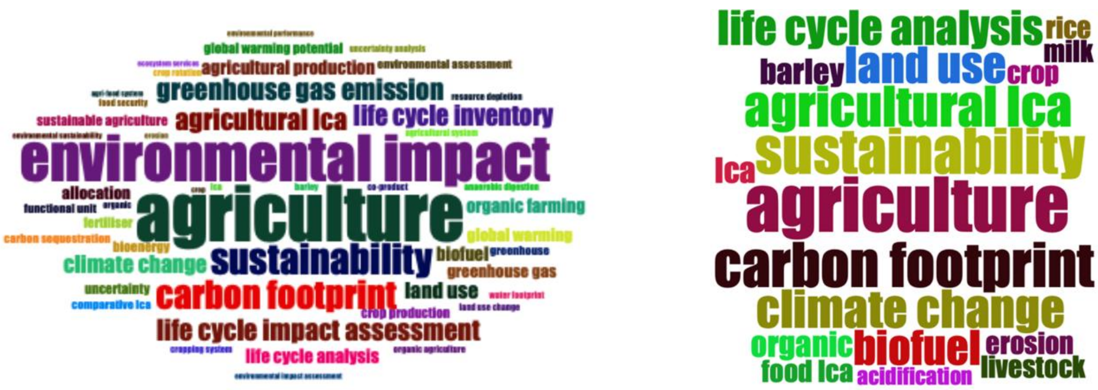


Figure 9. Top authors' production over time

Source: authors' development via Biblioshiny.

Most of these scholars are also the most cited: the author H-index in this collection for Nemecek, Gaillard, van der Werf, Basset-Mens, and Hayashi is 10, 8, 8, 6, 4, respectively. The most productive and relevant authors systematically researched LCA application in agriculture, starting from 2007–2008 (Gaillard and Hayashi began in 2010 and 2012, respectively) – Figure 9.

4.2. Research content. The word cloud reveals the research context, illustrating the most frequent words (Figure 10). The main corpus of research keywords consists of the following terms: "agriculture" (frequency is 31), "environmental impact" (26), "sustainability" (17), "carbon footprint" (16), "agricultural LCA" (12), "greenhouse gas emission" (12), "life cycle impact assessment" (12), "life cycle inventory" (11), "climate change" (10). In addition to the mentioned before, "biofuel", "land use", and "organic" are gaining popularity. In general, research mainly focuses on the environmental impact assessment of agriculture, the link between LCA and sustainability, climate issues, LCA of specific crops and livestock, and methodological issues (impact assessment, allocation, and life cycle analysis).



a) Frequency word occurrence measure *b) Log word occurrence measure*

Figure 10. Word cloud of author keywords

Source: authors' development via Biblioshiny.

The thematic map complements the description of research field development by disclosing the key concepts' prevalence and relevancy (Figure 11). The author keywords were used to cluster the documents. As a result, 11 clusters were obtained. The agricultural LCA research centres around the role of LCA in food security and agricultural sustainability, complemented by niche topics concerning bioenergy, irrigation, and nitrogen. Basic themes (in addition to "food security") include issues related to environmental impact and its assessment via LCA in agriculture, effects of climate change on agriculture and their mitigation ("global warming potential category"), and exploration of agricultural practices, systems, and products through LCA. Issues of LCA application to measure impacts related to resource depletion and inform agricultural policy represent niche themes that are less spread and relevant. Growing attention is given to LCA applications to measure greenhouse gas emissions and features of LCA procedures in agriculture ("agricultural LCA"). These themes drive the modern development of the research field.

The identified diversity of themes covered (Figure 11) proves the need to explore the historical evolution of the research field.

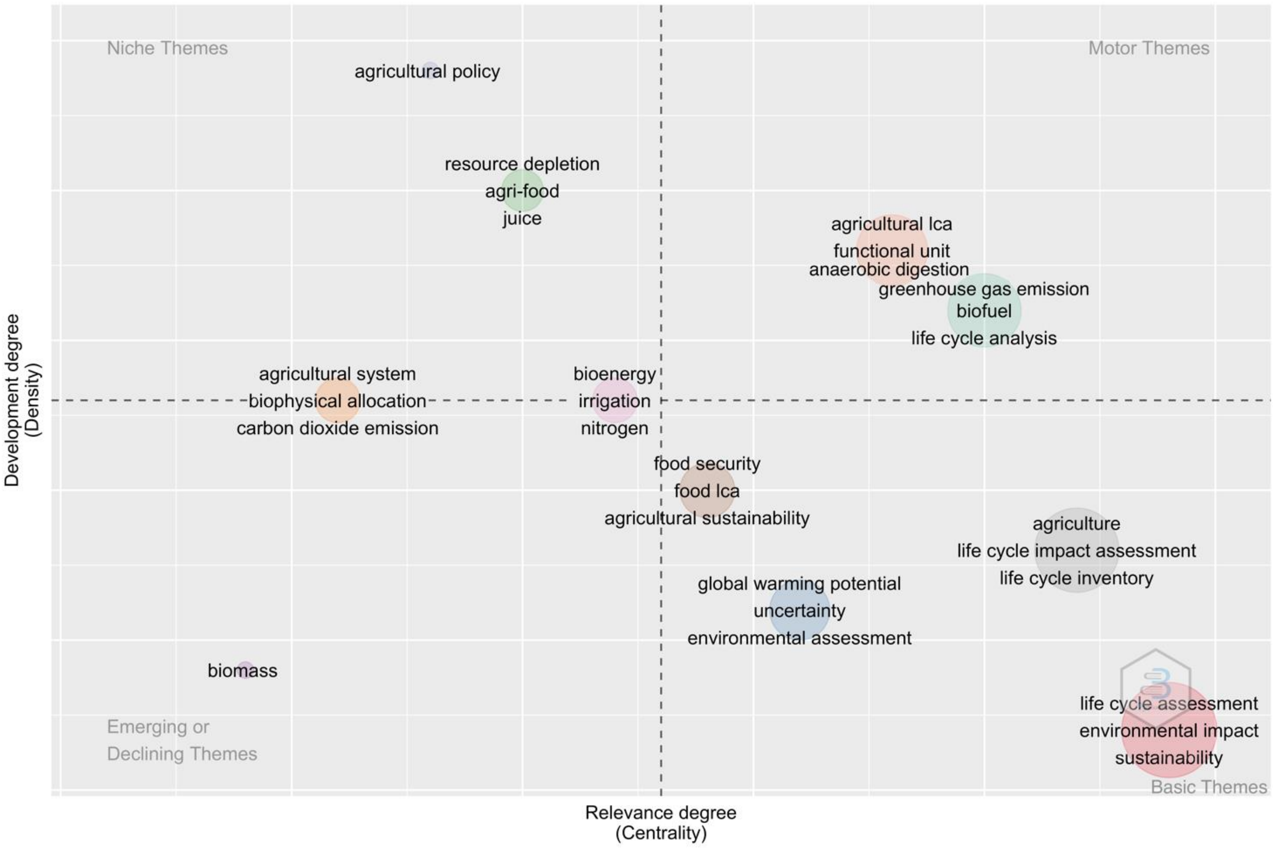


Figure 11. Thematic map by author keywords

Source: authors' development via Biblioshiny.

Thematic evolution map (by author keywords) is drawn according to previously identified time slices with the publication activity decline (2003–2004, 2008, 2016, 2019) (Figure 12). Scientific productivity decline followed by the increase may indicate the emergence of a new trend (new topic) in the research field.

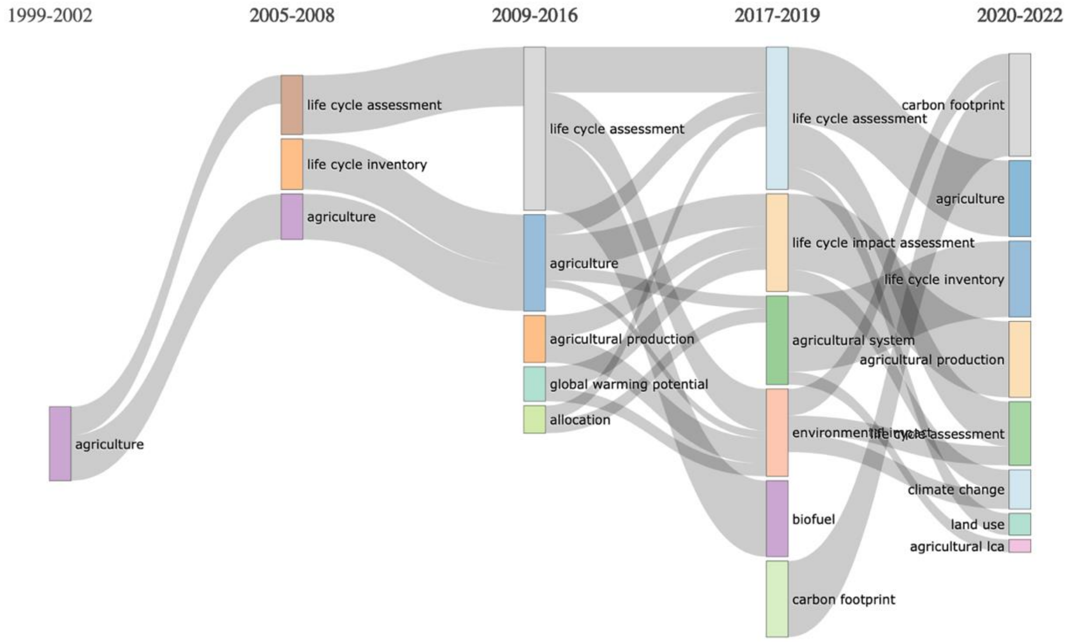


Figure 12. Thematic evolution map by author keywords

Source: authors' development via Biblioshiny.

The first period (1999–2002) indicates the emergence of agriculture as a new area for LCA studies that further (2005–2008) is complemented with the studies of methodological issues (life cycle inventory). In 2009–2016, new topics arose (global warming potential, allocation) with a focus on production. The systemic view of agriculture as an object of LCA marks 2017–2019, LCA's focus on environmental impact and biofuel, and the emergence of carbon footprint-related research. Research in the current period focuses on climate change issues, production side and methodological aspects (allocation, inventory, agricultural LCA).

4.3. Main research topics. For a brief overview of leading research areas, the documents were bibliographically coupled and clustered based on the Walktrap algorithm. Five clusters of studies were obtained (Figure 13). Clusters are labelled by the three most frequently used author keywords identified automatically from clustered papers. Normalised Global Citation Score measures clusters' impact. The circle size reflects the number of papers constituting the cluster. The broadest clusters are as follows: "life cycle assessment – conf 31.6 %" (81 documents), "life cycle assessment – conf 23.1 %" (55), and "life cycle assessment – conf 23.9 %" (63). The latter has the highest centrality and impact rates among them. Despite other clusters include fewer documents coupled by common references, they have the highest centrality ("life cycle assessment – conf 16.2 %") and impact ("life cycle assessment – conf 5.1 %") rates.

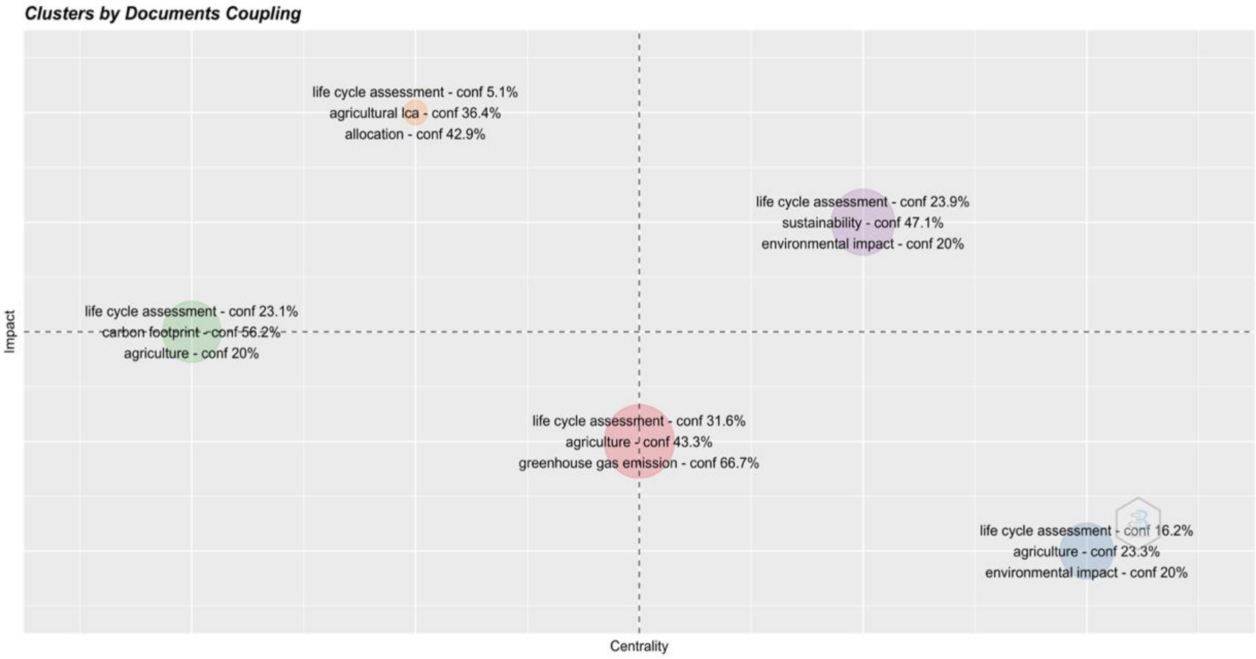


Figure 13. Documents' coupling map by references*

Note. *Centrality is measured by Callon's Centrality Index; Impact is measured by Normalised Global Citation Score; Conf – confidence level.

Source: authors' development via Biblioshiny.

To characterise the content of the research clusters, a sample of 20 articles was formed. The number of articles for each cluster was determined according to the cluster's share in the general sample. Articles for in-depth analysis were chosen by the total citations per year (the first most cited papers were selected). Due to the articles' content, clusters were retitled to provide an exact research theme characteristic.

LCA studies concerning sources and potential to reduce greenhouse gas emissions in agriculture. This cluster (coral coloured) combines the most significant number of studies (81) with an average number of citations per article within the group of 65 (5 per year). The focus is on greenhouse gases, considered the main LCA-based decision-making criterion for selecting agricultural measurements and development opportunities. Scientists investigate various aspects and components of greenhouse gases (GHG) and related issues: nitrogen emissions [41–43], aggregated greenhouse gases as a category of global warming potential [44], carbon storage potential and sequestration [45; 46]. Applying the GHG as a measure of agricultural systems (and supply chains) performance, scholars discuss the advantages and disadvantages of organic farming [41; 44; 45], fertilisation alternatives [43], crop rotation [42] and placement of farms [44; 45].

Given the importance of GHG control, Nemecek et al. [41] argue the importance of improvement of manure management systems in organic farming (authors investigate the integrated and organic system on the example of the Swiss land use and feed production via Swiss Agricultural Life Cycle Assessment method). They suggest applying a whole-farming system life cycle analysis in the case of organic farming to determine the primary sources of environmental impact (including manure management problems) and justify the superiority compared to an integrated production system (due to less resource consumption and better biodiversity protection) [41]. Following the need to control and decrease GHG in agriculture and related sectors, Nemecek et al. [42] look upon alternatives to supplying (importing) feed for European livestock production. The authors use the Swiss Agricultural Life Cycle Assessment approach to investigate the environmental impact of grain legumes implementation in the existing crop rotation system in Europe (Germany, France, Switzerland, and Spain). Scholars found this alternative suitable under the conditions of fossil fuels depletion and climate change because of the reduced nitrogen applications per area unit [42]. Hasler et al. [43] raise similar issues: nitrogen-reduced production is critical in promoting sustainable agriculture development. In the example of the German fertiliser supply chain (cradle-to-field), the authors found it possible to reduce the environmental impact of agriculture by 15 % via optimisation of the fertiliser application strategy and suggest controlling the level of nitrogen application and the way it is produced through the inclusion of these issues (fertilisers selection depending on their type) to every food LCA.

Meisterling et al. [44] argue that farm localisation is an essential factor influencing LCA-based decisions concerning organic or conventional farming and their impact measured by the global warming potential (GWP) category. Applying the hybrid flow LCA (economic input-output life cycle assessment), scholars conducted a comparative LCA of the whole-wheat flour supply chain (conventional and organic production and transportation to the point of sale) in the US. They found organic wheat production better regarding GWP per unit of food than conventional (synthetic nitrogen is a significant factor influencing production systems' environmental performance). But, the longer the delivery distance, the lower the benefits of organic farming. If organic products are delivered farther than 420 km from conventional, then the impact between them will be levelled [44]. Addressing the problem of reducing GHG emissions caused by food supply to the urban areas in the UK, Kulak et al. [45] use an LCA to investigate the feasibility of creating urban community farms in the London Borough of Sutton example. Food produced in those urban farms might replace products usually produced in energy-intensive greenhouses or delivered outside Europe by air transport. Scholars found urban farms to be a source of greenhouse gas savings compared to traditional food supply systems and justify the feasibility of replacing city parks with urban farms (carbon storage potential is higher by 34 %) [45].

The need to control GHG emissions and carbon storage potential also influences research on the LCA methodology and procedures. Investigating methods for assessing carbon sequestration within the LCA procedure for agricultural products, Petersen et al. [46] prove the need to account for the time variability of soil carbon accumulation for different production systems (200, 100, and 20 years). Authors argue that accounting for the time of carbon dioxide emissions and the carbon cycle can significantly affect LCA estimates. Following the proposed approach, they substantiate the advantages of leaving straw in the soil (instead of extracting it for energy production) in Denmark and the benefits of organic soybean cultivation in China, compared to traditional [46].

Variety of impacts covered by LCA in agriculture and agri-food chains. This cluster has the highest centrality rate but the average frequency and the least impact rate (Figure 13, blue coloured). It combines 44 documents in the collection with a broad scope of research issues covered: the importance of a full-scale LCA study in agriculture (covering all types of impacts and categories) [47], the need to combine LCA with other methods to better address various effects of agriculture [48], the failure of traditional LCA procedures (regarding social assessment) to cover the impact significant for SMEs and family farms [49]. To illustrate this, a brief overview of the representative articles (three articles according to the cluster frequency) is given.

Payen et al. [47] raise the question of the variability of LCA results depending on the category chosen as a parameter for evaluation. Taking as an example the alternatives of tomatoes supply chains in France (Morocco and France produced), authors demonstrate limitations of a single-indicator LCA (in particular, use of only greenhouse gas emissions) and emphasise the need for a more comprehensive approach: scholars show that inclusion of freshwater use category in LCA-based decision-making (due to water shortage in Morocco) leads to more sustainable solutions [47]. Deng et al. [48] focus on agriculture's effects on human health. Analysing the soil-rice-human blood chain of metals transfer (As, Pb, Cd, Hg, Cr) in China, authors emphasise that combining LCA with other methods (cluster analysis and positive matrix factorisation) provides proper assessment, prediction of metal accumulation in rice, and simulation of their transfer into human blood. Such an integrated methodology takes less time, is resource-consuming and allows for determining the sources of metals and predicting their transfer [48]. Arcese et al. [49], on the example of wine production in Italy (SMEs and family businesses), demonstrate the sector's sensitivity to the social aspects of agriculture (production, processing, and sale process). Scholars found the traditional social LCA categories insufficient to cover all social effects significant for SMEs (lack of subcategories related to the highest level of the needs' hierarchy) and form a reasonable theoretical basis for social LCA in industries related to food production, functioning of medium and small, family agribusiness [49].

Measuring the environmental impact of agricultural systems via LCA: challenges and contradictions. This cluster has an average frequency and combines about a fifth part of the documents from the collection (green coloured). Research in this cluster, being closely related to the environmental impacts of agriculture, covers the following issues: LCA's ability to measure the environmental effects of traditional and alternative (organic [50], upland [51]) farming systems comprehensively; complexity and multifaceted nature of agriculture influencing the specificity of LCA procedure [52]; interpretation of environmental LCA results according to the functional unit chosen [50–52]; possible solutions to minimise environmental impacts of urban food supply and substantiation of farms localisation decisions [53].

The representative articles within this cluster reveal the main discussion: the use of LCA to make decisions concerning the benefits and potential of organic farming to reduce the environmental impact of agriculture. Clark & Tilman [50] take the product as a functional unit and environmental impact estimates (via GHG emissions, land use, energy use, acidification potential, and eutrophication potential) of organic and traditional production systems and found organic farming to be advantageous only in reducing energy use. Scholars suggest the best solution to minimise the agriculture environmental impact via increasing the efficiency of traditional farming, especially in small farms, where the marginal effect of reducing the environmental impact due to increased efficiency of the inputs used is most noticeable [50]. Earlier research of Blengini & Busto [51] shows the variety of LCA results due to the functional unit selected: authors demonstrate – in the example of the rice supply chain (field-supermarket) in the Vercelli district in northern Italy – alternative systems (organic and upland farming) have the potential to decrease environmental impact (carbon dioxide emissions, primary energy, and water consumption) per unit of area. However, when measuring per unit of milled rice, environmental impact reducing the potential of alternative systems significantly decreases [51]. Suggestions for solving this problem are outlined by Notarnicola et al. [52]. The authors consider the close relationship of anthropogenic and environmental components in agriculture to be the central aspect determining the specifics of LCA regarding the system boundaries, allocation, and functional unit choice. The agriculture's multifunctionality (nutritional, economic, and social significance) and time-dispersed environmental effects of farming practices on soils and biodiversity need to be addressed (via proper soils' categorisation, use of different functional units), making LCA application in agriculture a unique procedure – the agricultural LCA [52]. Alongside the abovementioned research on agricultural systems' environmental impact, Benis & Ferrão [53] apply LCA to explore the potential of different measurements to reduce the environmental impact of the urban food system in the Lisbon Metropolitan Area, Portugal. Scholars found dietary changes, allowing to reduce of GHG emissions and land use, the most beneficial compared to reducing waste (more than twice lower reduction of GHG and land use) and suburban farming (about ten times lower reduction of GHG) [53].

Getting agriculture sustainability through the LCA. This cluster is ranged second from the top by the centrality and impact (purple colour). It integrates 63 articles covering different aspects of LCA's contribution to agriculture sustainability. The most cited within the cluster, paper by van der Werf et al. [54] raises the problem of limitations of traditional approaches to selecting a functional unit in agriculture (product-oriented) and the effects to be evaluated within the LCA. Scholars point out the inability of current LCA approaches to address agriculture's multifunctionality, complexity, and indirect effects. This can lead to incorrect decisions concerning agriculture's sustainability solutions (in particular, underestimating organic farming sustainability effects and performance). Scientists suggest using agro-ecological principles when defining a functional unit and developing models accounting for the indirect effects of agriculture when making LCA-based decisions promoting agriculture sustainability [54]. The problems mentioned were partially illustrated earlier by Salou et al. [55]. In the case of dairy farming (France), scholars found mass-based LCA environmental impact estimates favouring intensification, thereby increasing the industry's environmental impact. Authors suggest using two types (mass and area-based) of LCA to make well-informed decisions, especially comparing systems different by the level of intensification (e.g. low-input and high-input systems or organic and conventional) [55]. Assessing the environmental impact of traditional and organic rice production in Malaysia via LCA, Harun et al. [56] developed a conceptual scheme for sustainable rice production following the traditional three-pillar approach of sustainability interpretation. This scheme involves the use of social LCA, environmental LCA, and life cycle costing to develop policy measures that promote rice production sustainability [56].

Going beyond agriculture itself, Akhoundi & Nazif [57] propose another approach to make LCA more useful when elaborating sustainable solutions. Scientists use the example of a wastewater treatment plant in Tehran, Iran, to test the multi-criteria decision-making methodology based on the evidential reasoning approach, where LCA and life cycle costing are applied to assess the environmental impact and costs associated with wastewater reuse alternatives. This allows justifying wastewater reuse for agricultural irrigation as one of several alternatives with the best value and a much lower environmental impact than other alternatives [57]. Like the previous paper, the article by Agostini et al. [58] focuses on the combination and interrelationships of production processes and agricultural resources and their best use in and outside agriculture production. Applying environmental LCA and life cycle costing, authors evaluate and compare the parameters of agrivoltaics, photovoltaics, electricity mix, and biogas production systems in Italy, Po Valley, Lombardi. They found several environmental advantages of agrivoltaics (less land use and stabilisation of agricultural production). They provided a broader research context: the need to consider these aspects when analysing other (future) energy systems' feasibility against the background of increasing land use and climate change pressure [58].

Methodological issues of agricultural LCA. The cluster has the highest impact rate but integrates the least number of papers from the collection (orange colour). Two representative papers cover issues related to allocation procedures in agricultural LCA [59] and the increase of LCA comprehensiveness [60]. Emphasising the biological causality as an essential feature of agricultural systems, Mackenzie et al. [59] investigate the viability and challenges of biophysical allocation methods (compared to economic) in LCA for crop and multiple co-products livestock production systems. Scholars conclude that biophysical methods don't resolve the problem of allocation sensitivity to the economic value of functional output and point out the need to develop a consistent coproduct allocation method to account for the environmental impact of agricultural products [59]. Khoshnevisan et al. [60] suggest complementing LCA methodology with optimisation methods (multi-objective genetic algorithm (MOGA) and data envelopment analysis (DEA) to make results more comprehensive and valuable, contributing not only to the minimisation of environmental impacts but also to increased efficiency and better resource use, especially at the smallholder level. However, this approach has some limitations: it doesn't allow covering the entire chain and must be implemented at each stage separately [60].

5. DISCUSSION

The results illustrate the intensive development of the research field, evidencing the exponential growth of the number of publications on LCA in agriculture in high-quality academic journals. Alongside the scientific activity growth, this study identifies a tendency to continue and complement earlier research findings from 2000–2001, 2008, and 2017: these publications have the highest number of citations per article per year. This means a certain stability, continuity, and historic relationship within the studies in the research field analysed and corresponds with the periods of research interest growth measured by an increase in publication activity. The latter may indicate a set of important research topics founded in the highly cited papers of these years, laying the foundation for further studies. The third part of research on LCA in agriculture is carried out in environmental sciences, revealing the prevailing context – environmental aspects – corresponding to the traditional objectives of the LCA. During the period analysed, research on LCA in agriculture transformed from a highly specialised topic (published within a few academic journals initially) into a broader one: the number of journals for publication of research results and the variability of their scope increased significantly. Despite more than 40 % of the collection being published in two leading journals up to now (the Journal of Cleaner Production and the International Journal of Life Cycle Assessment), the new sources are also rapidly becoming influential (the Science of the Total Environment, the Sustainability (Switzerland), and the Agronomy), as measured by m-index score.

Developed countries are leading in this research field in terms of productivity and impact: France, the USA, Italy, Spain, and Switzerland. China's growing role in this area of scientific interest is evident, especially concerning international collaboration and leadership in multi-authored teams. However, agricultural LCA studies are highly concentrated and not equally distributed even within the EU (Eastern European countries have a few proper publications). The countries' collaboration is the closest within and between two clusters: Central European, led by France, Switzerland, and the UK and American-European, where the USA and Italy are the leaders. Other countries are weakly collaborating. The most productive institutions are entirely logical in Denmark, France, Switzerland, and the USA. In addition, independent researchers (without affiliation) also explore the LCA application in agriculture. The most productive and relevant scholars have been conducting research systematically since 2007–2008.

The main research content, highlighted by author keywords, involves issues like the environmental impact of agriculture, procedural aspects (inventory, impact assessment), LCA categories (greenhouse gas emissions, land use), methods (carbon footprint), impact of fertilisers (with an emphasis on nitrogen), organic production. Basic themes of agricultural LCA research involve studies on environmental impacts and climate change effects of agriculture (products, systems, practices). The impact of agriculture on resource depletion and the using LCA in the context of agricultural policy constitute niche topics. Dealing with greenhouse gas emissions and methodological aspects of LCA application in agriculture are topics leading the field of research. This is also reflected in the research evolution map: the carbon footprint, procedural aspects (inventory and impact assessment stages), and climate change shape the content of the current stage (2020–2022). Besides, the production side is getting more attention in the current research development phase, as the previous review [29] mentioned.

In general, the obtained results align with previous findings concerning the LCA expansion in agriculture and appropriate research growth [19; 20; 30; 28], and the leadership of developed countries [22; 28], despite the breadth of the studied context. As Fan et al. mentioned, several problems outlined in 2008–2011 remain unsolved: the problem of choosing a functional unit, allocation procedures, and setting the system boundaries [27] – but this research are not frequent. The practice of LCA application to compare different production systems (organic and conventional, extensive and intensive, small and large, traditional and developed), outlined by Ruviaro et al. [30] is found still relevant. However, the LCA application is expanded to compare urban and suburban food supply systems. Our review confirms the significance of environmental assessments and contexts of LCA studies in agriculture, like previous studies [25; 27]. Nevertheless, it shows the predominance of the narrower perspective – GHG-related evaluations and research. Though the attention to social and economic aspects in agricultural LCA studies is growing [6; 7], this topic is not significant. Integrating social and economic assessments is seen as one of the ways to make LCA more useful. Ruviaro et al. suggested earlier the integration of LCA with other methods to obtain better results in terms of environmental impact assessments [30]. Current LCA research explores integrating different assessments to get more comprehensive results (to adopt three-dimensional sustainable solutions). Moreover, integrating other methods with LCA is seen as a tool for including more deeply social and economic drivers [61] and to address the agriculture specifics (multifunctionality, complexity, and variety of effects) and support decision-making towards sustainability.

Additionally, a system-wide perspective allows for outlining the main areas within the agricultural LCA research. Results of documents clustering by references and an in-depth analysis of representative articles illustrate five main research directions. The most frequent are studies concentrating on GHG emissions in agriculture and related supply chains: scholars take GHG emissions (evaluated via LCA) as a measure of the feasibility of agricultural products, practices, and systems and the central area of improvement. Research investigating the variety of LCA-covered agriculture's effects has an average frequency but the least cluster impact rate. There is a pretty diverse group of articles covering issues like a single-indicator LCA inconsistency in agriculture (in contrast to the previous group of research), LCA potential to trace and predict the agriculture-related impacts on human health in the long run, and social LCA methodology's adaptation to the small farming context. Papers exploring LCA of agriculture's environmental impacts constitute the fifth part of the collection; the main discussion in this cluster centres around the assessment and interpretation of organic and traditional farming environmental impacts (the hotspot is the functional unit choice). The research focused on the potential of LCA to support sustainable solutions in agriculture involves papers discussing the multifunctionality and complexity of agriculture and the need to improve the LCA methodology by incorporating social and economic assessments and other decision-making methods. This direction is second from the top by frequency. The methodological discussion cluster – investigating allocation procedures and applying additional methods to support LCA comprehensiveness – is the least frequent but has the highest impact rate.

6. CONCLUSIONS

In conclusion, a system-wide overview of agricultural LCA research, which covered various areas of agriculture and LCA methods, reveals that LCA in agriculture focuses on greenhouse gases as a separate impact category. This means significant attention to research on agricultural practices that could contribute to carbon sequestration in soils and food chain shortening (to minimise transport operations and associated emissions). However, this doesn't cover all aspects of agriculture and overall sustainability (relationship between land use for food, feed, energy, and other resources, impact on ecosystems and local communities, etc.). Integrating social and economic aspects within traditional LCA study and using other methods to ensure the comprehensiveness of LCA estimates and well-informed decisions can solve the problem of ambiguity of results and interpretations of environmental LCA. This may constitute a future direction of research on LCA application in agriculture.

Generalising the research results and looking upon them in the context of previous studies, one should emphasise the "closeness" of the research community manifested in the highest citation rates of earlier publications, the patterns of countries' collaboration, the journals involved in the publication of research results, the existence of problems regarding the LCA procedures in agriculture mentioned earlier but still being unresolved. Despite the growing publication activity, research progress is weak. Sharing knowledge and LCA tools, initiating a discussion involving actors and partners globally [62; 63], and investigating the policy applications, benefits, and regulations promoting agricultural LCA expansion may help to solve this problem and give a new breath to the research field.

7. LIMITATIONS AND FUTURE RESEARCH

The main limitation of the study is the database and language limitations. Covering only Scopus-indexed English-language academic papers could lead to excluding relevant research and contexts. However, the comprehensive coverage of the selected database and its overlap with others allows for generalising the research conclusions.

Revealing the "closedness" of the research community, this review stresses the need to expand agricultural LCA research and practices. Studies from developing countries can enrich existing LCA results and contribute to developing LCA methodology in agriculture through evidence-based practices and research. Clarifying the reasons for the lack of research development in other countries and elaborating measures to promote LCA application in agriculture worldwide needs more attention from scholars and policymakers.

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REFERENCES

1. The World Bank (2022). Agriculture and food overview. Available at: https://www.worldbank.org/en/topic/agriculture/overview#2.

2. Climate Watch Data (2022). Agriculture total emissions in 2019. Available at: https://www.climatewatchdata.org/sectors/agriculture#drivers-of-emissions.

3. The World Bank Data (2022). Agriculture and rural development in 2019. Available at: https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?view=chart.

4. Sieverding, H., Kebreab, E., Johnson, J. M. F., Xu, H., Wang, M., Grosso, S. J. D., Bruggeman, S., … & Stone, J. J. (2020). A life cycle analysis (LCA) primer for the agricultural community. *Agronomy Journal*, 112(5), 3788–3807. https://doi.org/10.1002/agj2.20279.

5. Huertas-Valdivia, I., Ferrari, A. M., Settembre-Blundo, D., & García-Muiña, F. E. (2020). Social life-cycle assessment: a review by bibliometric analysis. *Sustainability*, 12(15), 6211. https://doi.org/10.3390/su12156211.

6. Degieter, M., Gellynck, X., Goyal, S., Ott, D., & De Steur, H. (2022). Life cycle cost analysis of agri-food products: a systematic review. *Science of The Total Environment*, 850, 158012. https://doi.org/10.1016/j.scitotenv.2022.158012.

7. De Menna, F., Dietershagen, J., Loubiere, M., & Vittuari, M. (2018). Life cycle costing of food waste: a review of methodological approaches. *Waste Management*, 73, 1–13. https://doi.org/10.1016/j.wasman.2017.12.032.

8. Kalachevska, L., Koblianska, I., & Holzner, J. (2022). Concept and measurement of the food system sustainability: a bibliometric research. *Scientific Horizons*, 25(1), 104–119. https://doi.org/10.48077/scihor.25(1).2022.104-119.

9. Cucurachi, S., Scherer, L., Guinée, J., & Tukker, A. (2019). Life cycle assessment of food systems. *One Earth*, 1(3), 292–297. https://doi.org/10.1016/j.oneear.2019.10.014.

10. Caffrey, K. R., & Veal, M. W. (2013). Conducting an agricultural life cycle assessment: challenges and perspectives. *The Scientific World Journal*, 2013, 1–13. https://doi.org/10.1155/2013/472431.

11. Klymchuk, O., Khodakivska, O., Kovalov, B., Brusina, A., Benetyte, R., & Momotenko, I. (2020). World trends in bioethanol and biodiesel production in the context of sustainable energy development. *International Journal of Global Environmental Issues*, 19(1–3), 90–108. https://doi.org/10.1504/ijgenvi.2020.114867.

12. Bornmann, L., Haunschild, R., & Mutz, R. (2021). Growth rates of modern science: a latent piecewise growth curve approach to model publication numbers from established and new literature databases. *Humanities and Social Sciences Communications*, 8(1), 224. https://doi.org/10.1057/s41599-021-00903-w.

13. Higgins, J. P. T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (Ed.). (2022). Cochrane Handbook for Systematic Reviews of Interventions. Version 6.3. Cochrane. Available at: www.training.cochrane.org/handbook.

14. Pereira, O. P., Goncharenko, O., Chortok, Y., Kubatko, O. V., & Coutinho, M. M. (2021). Service learning as an educational outreach project for community's sustainable development and social responsibility support. *International Journal of Global Environmental Issues*, 19(1–3), 53–69. https://doi.org/10.1504/ijgenvi.2020.114865.

15. Baldini, C., Gardoni, D., & Guarino, M. (2017). A critical review of the recent evolution of life cycle assessment applied to milk production. *Journal of Cleaner Production*, 140, 421–435. https://doi.org/10.1016/j.jclepro.2016.06.078.

16. Blanco, I., De Bellis, L., & Luvisi, A. (2022). Bibliometric mapping of research on life cycle assessment of olive oil supply chain. *Sustainability*, 14(7), 3747. https://doi.org/10.3390/su14073747.

17. Rapa, M., & Ciano, S. (2022). A review on life cycle assessment of the olive oil production. *Sustainability*, 14(2), 654. https://doi.org/10.3390/su14020654.

18. Cellura, M., Cusenza, M. A., Longo, S., Luu, L. Q., & Skurk, T. (2022). Life cycle environmental impacts and health effects of protein-rich food as meat alternatives: a review. *Sustainability*, 14(2), 979. https://doi.org/10.3390/su14020979.

19. Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N., & Shiina, T. (2009). A review of life cycle assessment (LCA) on some food products. *Journal of Food Engineering*, 90(1), 1–10. https://doi.org/10.1016/j.jfoodeng.2008.06.016.

20. Schau, E. M., & Fet, A. M. (2008). LCA studies of food products as background for environmental product declarations. *The International Journal of Life Cycle Assessment*, 13(3), 255–264. https://doi.org/10.1065/lca2007.12.372.

21. Takacs, B., & Borrion, A. (2020). The use of life cycle-based approaches in the food service sector to improve sustainability: a systematic review. *Sustainability*, 12(9), 3504. https://doi.org/10.3390/su12093504.

22. Tamasiga, P., Miri, T., Onyeaka, H., & Hart, A. (2022). Food waste and circular economy: challenges and opportunities. *Sustainability*, 14(16), 9896. https://doi.org/10.3390/su14169896.

23. Omolayo, Y., Feingold, B. J., Neff, R. A., & Romeiko, X. X. (2021). Life cycle assessment of food loss and waste in the food supply chain. *Resources, Conservation and Recycling*, 164, 105119. https://doi.org/10.1016/j.resconrec.2020.105119.

24. Molina-Besch, K., Wikström, F., & Williams, H. (2019). The environmental impact of packaging in food supply chains – does life cycle assessment of food provide the full picture? *The International Journal of Life Cycle Assessment*, 24(1), 37–50. https://doi.org/10.1007/s11367-018-1500-6.

25. Vidergar, P., Perc, M., & Lukman, R. K. (2021). A survey of the life cycle assessment of food supply chains. *Journal of Cleaner Production*, 286, 125506. https://doi.org/10.1016/j.jclepro.2020.125506.

26. Talwar, N., & Holden, N. M. (2022). The limitations of bioeconomy LCA studies for understanding the transition to sustainable bioeconomy. *The International Journal of Life Cycle Assessment*, 27(5), 680–703. https://doi.org/10.1007/s11367-022-02053-w.

27. Fan, J., Liu, C., Xie, J., Han, L., Zhang, C., Guo, D., Niu, J., … & McConkey, B. G. (2022). Life cycle assessment on agricultural production: a mini review on methodology, application, and challenges. *International Journal of Environmental Research and Public Health*, 19(16), 9817. https://doi.org/10.3390/ijerph19169817.

28. Alhashim, R., Deepa, R., & Anandhi, A. (2021). Environmental impact assessment of agricultural production using LCA: a review. *Climate*, 9(11), 164. https://doi.org/10.3390/cli9110164.

29. Gava, O., Bartolini, F., Venturi, F., Brunori, G., & Pardossi, A. (2020). Improving policy evidence base for agricultural sustainability and food security: a content analysis of life cycle assessment research. *Sustainability*, 12(3), 1033. https://doi.org/10.3390/su12031033.

30. Ruviaro, C. F., Gianezini, M., Brandão, F. S., Winck, C. A., & Dewes, H. (2012). Life cycle assessment in Brazilian agriculture facing worldwide trends. *Journal of Cleaner Production*, 28, 9–24. https://doi.org/10.1016/j.jclepro.2011.10.015.

31. Claudino, E. S., & Talamini, E. (2013). Análise do Ciclo de Vida (ACV) aplicada ao agronegócio: Uma revisão de literatura. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 17(1), 77–85. https://doi.org/10.1590/S1415-43662013000100011.

32. Falagas, M. E., Pitsouni, E. I., Malietzis, G. A., & Pappas, G. (2008). Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses. *The FASEB Journal*, 22(2), 338–342. https://doi.org/10.1096/fj.07-9492LSF.

33. Singh, V. K., Singh, P., Karmakar, M., Leta, J., & Mayr, P. (2021). The journal coverage of Web of Science, Scopus and Dimensions: a comparative analysis. *Scientometrics*, 126(6), 5113–5142. https://doi.org/10.1007/s11192-021-03948-5.

34. Kalachevska, L., Koblianska, I., & Schlauderer, R. (2023). Bibliographic collection: agriculture-related LCA research from Scopus database (October, 3, 2023). Zenodo. https://doi.org/10.5281/zenodo.8132870.

35. Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, 133, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070.

36. Mukherjee, D., Lim, W. M., Kumar, S., & Donthu, N. (2022). Guidelines for advancing theory and practice through bibliometric research. *Journal of Business Research*, 148, 101–115. https://doi.org/10.1016/j.jbusres.2022.04.042.

37. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., … & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic Reviews*, 10(1), 89. https://doi.org/10.1186/s13643-021-01626-4.

38. RStudio Team (2020). *RStudio: Integrated Development for R*. RStudio, PBC, Boston, MA. Available at: http://www.rstudio.com.

39. R Core Team (2014). *R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria*. Available at: http://www.R-project.org.

40. Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, 11(4), 959–975. Available at: https://ideas.repec.org/a/eee/infome/v11y2017i4p959-975.html.

41. Nemecek, T., Dubois, D., Huguenin-Elie, O., & Gaillard, G. (2011). Life cycle assessment of Swiss farming systems: I. Integrated and organic farming. *Agricultural Systems*, 104(3), 217–232. https://doi.org/10.1016/j.agsy.2010.10.002.

42. Nemecek, T., von Richthofen, J.-S., Dubois, G., Casta, P., Charles, R., & Pahl, H. (2008). Environmental impacts of introducing grain legumes into European crop rotations. *European Journal of Agronomy*, 28(3), 380–393. https://doi.org/10.1016/j.eja.2007.11.004.

43. Hasler, K., Bröring, S., Omta, S. W. F., & Olfs, H.-W. (2015). Life cycle assessment (LCA) of different fertilizer product types. *European Journal of Agronomy*, 69, 41–51. https://doi.org/10.1016/j.eja.2015.06.001.

44. Meisterling, K., Samaras, C., & Schweizer, V. (2009). Decisions to reduce

greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat. *Journal of Cleaner Production*, 17(2), 222–230. https://doi.org/10.1016/j.jclepro.2008.04.009.

45. Kulak, M., Graves, A., & Chatterton, J. (2013). Reducing greenhouse gas emissions with urban agriculture: a life cycle assessment perspective. *Landscape and Urban Planning*, 111(1), 68–78. https://doi.org/10.1016/j.landurbplan.2012.11.007.

46. Petersen, B. M., Knudsen, M. T., Hermansen, J. E., & Halberg, N. (2013). An approach to include soil carbon changes in life cycle assessments. *Journal of Cleaner Production*, 52, 217–224. https://doi.org/10.1016/j.jclepro.2013.03.007.

47. Payen, S., Basset-Mens, C., & Perret, S. (2015). LCA of local and imported tomato: an energy and water trade-off. *Journal of Cleaner Production*, 87(1), 139–148. https://doi.org/10.1016/j.jclepro.2014.10.007.

48. Deng, M., Zhu, Y., Shao, K., Zhang, Q., Ye, G., & Shen, J. (2020). Metals source apportionment in farmland soil and the prediction of metal transfer in the soil-rice-human chain. *Journal of Environmental Management*, 260, 110092. https://doi.org/10.1016/j.jenvman.2020.110092.

49. Arcese, G., Lucchetti, M. C., & Massa, I. (2017). Modeling social life cycle assessment framework for the Italian wine sector. *Journal of Cleaner Production*, 140, 1027–1036. https://doi.org/10.1016/j.jclepro.2016.06.137.

50. Clark, M., & Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environmental Research Letters*, 12(6), 064016. https://doi.org/10.1088/1748-9326/aa6cd5.

51. Blengini, G. A., & Busto, M. (2009). The life cycle of rice: LCA of alternative agri-food chain management systems in Vercelli (Italy). *Journal of Environmental Management*, 90(3), 1512–1522. https://doi.org/10.1016/j.jenvman.2008.10.006.

52. Notarnicola, B., Sala, S., Anton, A., McLaren, S. J., Saouter, E., & Sonesson, U. (2017). The role of life cycle assessment in supporting sustainable agri-food systems: a review of the challenges. *Journal of Cleaner Production*, 140, 399–409. https://doi.org/10.1016/j.jclepro.2016.06.071.

53. Benis, K., & Ferrão, P. (2017). Potential mitigation of the environmental impacts of food systems through urban and peri-urban agriculture (UPA) – a life cycle assessment approach. *Journal of Cleaner Production*, 140, 784–795. https://doi.org/10.1016/j.jclepro.2016.05.176.

54. van der Werf, H. M. G., Knudsen, M. T., & Cederberg, C. (2020). Towards better representation of organic agriculture in life cycle assessment. *Nature Sustainability*, 3(6), 419–425. https://doi.org/10.1038/s41893-020-0489-6.

55. Salou, T., Le Mouël, C., & van der Werf, H. M. G. (2017). Environmental impacts of dairy system intensification: the functional unit matters! *Journal of Cleaner Production*, 140, 445–454. https://doi.org/10.1016/j.jclepro.2016.05.019.

56. Harun, S. N., Hanafiah, M. M., & Aziz, N. I. H. A. (2021). An LCA-Based environmental performance of rice production for developing a sustainable agri-food system in Malaysia. *Environmental Management*, 67(1), 146–161.

https://doi.org/10.1007/s00267-020-01365-7.

57. Akhoundi, A., & Nazif, S. (2018). Sustainability assessment of wastewater reuse alternatives using the evidential reasoning approach. *Journal of Cleaner Production*, 195, 1350–1376. https://doi.org/10.1016/j.jclepro.2018.05.220.

58. Agostini, A., Colauzzi, M., & Amaducci, S. (2021). Innovative agrivoltaic systems to produce sustainable energy: an economic and environmental assessment. *Applied Energy*, 281, 116102. https://doi.org/10.1016/j.apenergy.2020.116102.

59. Mackenzie, S. G., Leinonen, I., & Kyriazakis, I. (2017). The need for co-product allocation in the life cycle assessment of agricultural systems – is "biophysical" allocation progress? *International Journal of Life Cycle Assessment*, 22(2), 128–137. https://doi.org/10.1007/s11367-016-1161-2.

60. Khoshnevisan, B., Bolandnazar, E., Shamshirband, S., Shariati, H. M., Anuar, N. B., & Mat Kiah, M. L. (2015). Decreasing environmental impacts of cropping systems using life cycle assessment (LCA) and multi-objective genetic algorithm. *Journal of Cleaner Production*, 86, 67–77. https://doi.org/10.1016/j.jclepro.2014.08.062.

61. Tu, Y.-X., Kubatko, O., Piven, V., Kovalov, B., & Kharchenko, M. (2023). Promotion of sustainable development in the EU: social and economic drivers. *Sustainability*, 15(9), 7503. https://doi.org/10.3390/su15097503.

62. Afanasieva, O., Leonov, O., & Leonova, T. (2023). Marketing strategic analysis of the agricultural industry of Ukraine during the war. *Mechanism of an Economic Regulation*, 2(100), 23–28. https://doi.org/10.32782/mer.2023.100.04.

63. Stoliarchuk, N. (2023). Integration of Ukrainian agricultural science into the global environment. *Mechanism of an Economic Regulation*, 4(102), 47–51. https://doi.org/10.32782/mer.2023.102.08.

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