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Global Development on LCA Research:
A Bibliometric Analysis From 2010 to 2021

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ABSTRACT

Research on life cycle assessment (LCA) has been conducted over three decades. According to ISO 14040, LCA is an international standard that provides a methodology for assessing the environmental impact of products and processes. In the context of this study, research papers relevant to LCA are evaluated to conduct a bibliometric analysis of the LCA study from 2010 to 2021. The scope of this inquiry is confined to the Web of Science database of scientific papers. This analysis considers the authors' identification, type of articles, discipline, journal, citation, and bibliometric analysis components. Statistics of the most productive authors, institutions, and countries are also presented. The United States is the leading country in this field of LCA study. In addition, the word cloud and word dynamics are also evaluated. The bibliometric information is represented graphically in the bibliographic connection and co-citation network. This study will aid scholars in gaining systematic knowledge and comprehension of LCA research and its consequences.

KEYWORDS

Author Keywords, Bibliometric Analysis, ISO 14040, LCA, Life Cycle Assessment, Sustainability, Trending Topic, Web of Science

INTRODUCTION

The effects of global warming and other environmental problems have become more widely recognized in recent years. In order to handle these problems, businesses, consumers, governmental organizations, and legislators must take environmental factors into account while making a variety of decisions. (Nilsson and Eckerberg, 2007). A life cycle assessment is a technique for identifying the

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appropriate environmental consequences and resources consumed throughout a product's life, i.e., from procurement of raw materials to manufacturing and consumption, and finally, to waste management. The waste management step comprises both disposal and recycling. The term "product" refers to both products and services. LCA is a thorough assessment that considers all environment ecosystems, public health, and resources (ISO 14040, 2006). In LCA, the main thing that makes it different is that it looks at products from their whole lives. LCA's broader context is helpful for minimizing issues, such as from one stage of the life cycle to another, from one territory to another, or from one environmental problem to another. During the 1990s, interest in LCA surged, primarily when the first research papers were published. It was widely anticipated when LCA was first introduced, but its findings were also widely questioned. Since then, there has been significant development and standardization, emerging in global standards, which is supplemented by a series of recommendations. This has made LCA more mature and more stable in its methods and techniques. However, the approach is currently being refined. In the last few years, life cycle assessment (LCA) has been an excellent way to ensure that the environment isn't harmed during different phases of the process or products and figure out how to make things better (Rasheed et al., 2021). LCA is thought of as holistic, which helps people figure out the environmental effects of a product and helps them figure out how to reduce those effects and look for ways to make things more environmentally friendly (Gaete-Morales et al., 2019).

LCA study is divided into four phases: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation. The description of the goal and scope involves explaining why the study is being done, how it will be used, and who it will be for (ISO 14040, 2006). Additionally, this section describes the study's system boundaries and defines the functional unit. The functional unit is a quantifiable assessment of the goods (or service) activities. The LCI produces a collection of the product's inputs (resources) and outputs (emissions) over its life cycle in respect to the functional unit. The LCIA tries to examine and assess the extent and importance of the investigated systems through possible environmental impacts (ISO 14040, 2006). In the Interpretation phase, the outcomes from the preceding phases are reviewed in connection to the purpose and scope to gather information and suggestions (ISO 14040, 2006). In the current literature, several researchers presented LCA studies in their core areas like captive power plants (Dangayach et al., 2022); residential buildings (Sakhlecha et al., 2021); bar soap production (Gaurav et al., 2023); wastewater treatment plants (Mishra et al., 2021) and marble processing plant (Prajwal et al., 2019).

Presently, the literature on life cycle assessment (LCA) appears to be developing at a pace that can be seen with the naked eye. Numerous academics have expressed an interest in the advancement of this scientific topic. Because of their depth of knowledge, conventional systematic literature reviews are frequently used in peer-reviewed literature. However, literary studies often need a reviewer to have a high level of understanding. The digitization of scholarly journals has speed up the paper production process, culminating in a traditional organized literature analytical approach that can no longer deal with hundreds or even thousands of articles. Furthermore, certain crucial studies may be missed due to manual screening (Wang et al., 2020). As a result, methods for providing a high-level and comprehensive evaluation of the current status of research in LCA and its consequences must be developed.

The concept of bibliometrics has been around since the twentieth century (Zhou et al., 2018). It effectively assesses the influence of relevant scientific advancement in the field through several quantitative measurements (Marvuglia et al., 2020). Bibliometrics is widely accepted as one of the best tools for revealing how a particular area or discipline's knowledge base has accrued and developed, as well as the ties that connect it to other fields and disciplines (Donthu et al., 2021; gaurav et al., 2021a; Yadav et al., 2020; gaurav et al., 2021b). The outcomes' dependability is ensured through a comprehensive and consistent assessment process. Subjective bias is minimized by relying on computer-generated objective assessments rather than manual ones (Bretas et al., 2021). Bibliometrix (Aria and Cuccurullo, 2017), VOSviewer (Van Eck et al., 2010), and other prominent bibliometric

software tools are employed in the literature review. A wide range of bibliometric research in many topics and perspectives has been carried out using these valuable tools.

This work aims to present a relatively cohesive information architecture of the LCA literature and investigate the characteristics of LCA using a bibliometric evaluation. This study has two basic goals: (1) to analyze the intellectual landscape of LCA publications, (2) to identify the influential keywords of LCA. This bibliometric evaluation integrates VOS viewer and Bibliometrix tools to accomplish these objectives, with information being acquired through the Web of Science (WoS) database. The following is the outline of the paper. Section 2 summarizes the materials and methods utilized in the analysis and summarizes the classification process for the LCA themes. Section 3 gives the findings of the bibliometric study, followed by appropriate infographics; Section 4 describes the conclusions.

MATERIALS AND METHODOLOGY

This research aims to identify and analyze the scientific research and activities associated with LCA and uncover the factors of LCA.

Methods and Data Collection

A search technique was conducted on the WoS databases to obtain the literature data. WoS has become the major source of information for bibliometric analysis over time because it has a lot of information about citations from a wide range of fields (Zhang et al., 2020). It enables scholars to gather and obtain vast amounts of bibliographic data from a broad range of credible journals. As soon as the database has been chosen, the collection strategy needs to be implemented. The search method was carried out based on the research framework. The search string was chosen in such a way that it might encompass any title that contained all or some of the terms associated with LCA. During the search, the article title was used in the search field. The specific search form is as follows "LCA" OR "Life cycle assessment*" OR "life cycle analys*" OR "life cycle sustainability assessment*" OR "life cycle sustainability analysis." There were 7926 records retrieved for the literature data from the WoS database. After that, some data screening was completed as the final stage. The original dataset had some redundant entries. As a result, the redundant data were eliminated using the bibliometric tool. Simultaneously, various subjective inspections and assessments were conducted on every article to verify relevance to the LCA area. Seven thousand five hundred twenty-two academic journals had been screened.

Analysis Strategies

In bibliometric analysis, many historical reported literature is looked at to help researchers figure out what research is going on in a specific field. This study looks at the entire demographics of the literature, including the number of articles, prominent journals, regions, and writers. Secondly, citation analysis determines the most frequently cited articles and sources. Citation analysis can assist us in determining the significance of the individual study and determining which research areas attract the most emphasis in this area. Additionally, keywords typically include important research information in a single article. As a result, keyword analysis is utilized to uncover research hotspots and trends in this domain. Bibliometrix is a unique open-source tool for performing thorough scientific mapping analyses. It is written in the R programming language. The findings imported from WoS databases were analyzed using Bibliometrix (Aria and Cuccurullo, 2017), VOSviewer (Van Eck et al., 2010).

RESULTS AND DISCUSSION

The scientific architecture for LCA publications is laid out in this section, comprising five segments providing the spatial portrayal. Many interesting analyses and conclusions come up when you look

at the year, the author and journal, the geographical, the citations, and keywords. As a result, the LCA research community's expertise, knowledge, and trends are identified and depicted. The search criteria yielded 7926 WoS records. The repositories' articles were the primary data source for this study. This number may change over time as the WoS database is routinely refreshed. That's why the search date should be noted. Table 1 shows the extracted main information from the WoS database. Table 2 shows the distribution of documents. LCA research is constantly evolving and dynamic. As a result, the frequency of document types was examined, and thirteen distinct document types were discovered among the 7522 documents published between 2010 and 2021. Journals articles were the most frequently published document type, accounting for 85.02 percent of the documents (6395 publications), followed by editorial material, which accounted for 141 documents (1.87 percent) in the selected publications.

Statistics of LCA Publications

Table 3 depicts the chronological patterns of total publication (N), % Contribution, Total citations (TC), and Citable Years on LCA research. The first document on LCA was published in 1991. Figure 1 depicts the number of articles published and TC over time. This initial research was undertaken

Table 1. Extracted primary information from WoS database

Description	Results
Timespan	2010:2021
Sources (Journals, Books, etc)	820
Documents	7522
Average years from publication	5.18
Average citations per documents	24.44
Average citations per year per doc	3.466

Table 2. Distribution of documents

Documents Type	Records	% Contributions
Article	6395	85.02
Book Chapter	3	0.04
Early Access	80	1.06
Proceedings Paper	117	1.56
Biographical-Item	1	0.01
Book Review	5	0.07
Correction	78	1.04
Editorial Material	141	1.87
Letter	42	0.56
Meeting Abstract	142	1.89
News Item	3	0.04
Review	501	6.66
Review; Book Chapter	3	0.04

to determine the overall number of publications in LCA since 1990. Since 2010, a total of 7522 documents have been retrieved for the search. Between 1980 and 2000, the annual total of articles was significantly less. Nevertheless, between 2010 and 2021, the overall amount of literature increased significantly, surpassing 7522 overall publications. Additionally, the exponential growth in the number of papers on LCA reflects academics' interest in the field and a global trend toward sustainable energy consumption. Similarly, following the Kyoto Protocol, green technologies for product/process development were pushed to grow environmental consciousness and its frontal.

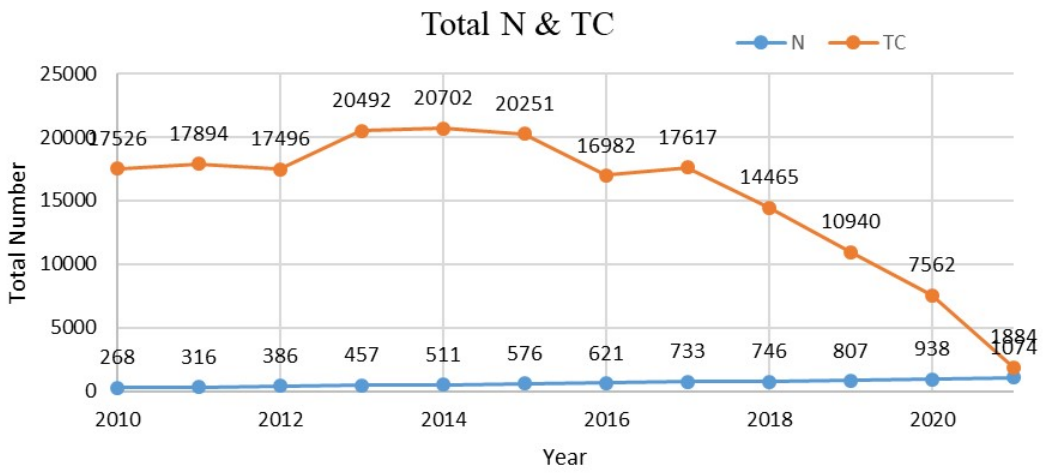
Statistics of Nation's Contribution and Collaboration on LCA

Several research is being conducted in various nations to concentrate on the innovation, inventory database creation, and application of the LCA. Several authors are likely to require additional assistance

Table 3. Annual production of documents

Year	Total Publication	% Contribution	Mean TC per Article	Mean TC per Year	Citable Years
2010	268	3.56	65.40	5.45	12
2011	316	4.20	56.63	5.15	11
2012	386	5.13	45.33	4.53	10
2013	457	6.08	44.84	4.98	9
2014	511	6.79	40.51	5.06	8
2015	576	7.66	35.16	5.02	7
2016	621	8.26	27.35	4.56	6
2017	733	9.74	24.03	4.81	5
2018	746	9.92	19.39	4.85	4
2019	807	10.73	13.56	4.52	3
2020	938	12.47	8.06	4.03	2
2021	1074	14.28	1.75	1.75	1

Figure 1. Number of articles published and TC over time



for research activity from participating nations to research in this field. Globally co-authored articles and collaboration can meet a research demand. It is crucial to determine nations or organizations focusing on LCA development and perform additional studies in this area. This enables nations involved in LCA to collaborate more effectively, engage in dialogue, and collaborate.

Researchers from 104 different nations wrote the 7522 documents on LCA-based studies. Table 4 and Figure 2 show the topmost productive nations. The USA (1056 articles, 52 percent), China (778 articles, 38 percent), Italy (632 articles, 27 percent), Spain (472 articles, 22 percent), Germany (384 articles, 18 percent), and France (312 articles, 18 percent) contributed the most. The occurrence and variety of participating nations demonstrate that the LCA has received widespread prominence, with submissions from all around the globe being published.

A globe map is the best way to visualize the country scientific production analysis. Additionally, such mapping can be used to analyze locations with a high research production level. Figure 3 depicts the proportions of country-specific publishing on a global map, alongside their overall publication indicated on the diagram. Mapping of scientific investigation shows that developed nations like the USA, France, Italy, Spain, Germany, and the UK, followed by underdeveloped countries like China, Brazil, and India dominate the LCA field.

The authors' nations are heavily clustered in advanced economies. Table 5 depicts the most cited nations in the field of LCA. The USA (29508 TC, 27.94 AAC, 16.05 percent), China (14915 TC, 19.17 AAC, 8.11 percent), Italy (16497 TC, 26.10 AAC, 8.97 percent), Spain (13463 TC, 28.52 AAC, 7.32 percent), and Germany (9957 TC, 25.93 AAC, 5.42 percent), cited the most.

Figure 4 depicts international scientific collaboration. The diameter of its bubble shows every nation's participation in LCA-based studies. A connection between the two bubbles in research papers shows how nations are linked globally. Collaboration between nations is evident, and five Nations

Table 4. Most productive nations

Rank	Country	Articles	SCP	MCP	MCP_Ratio
1	USA	1056	846	210	0.199
2	China	778	551	227	0.292
3	Italy	632	472	160	0.253
4	Spain	472	304	168	0.356
5	Germany	384	290	94	0.245
6	France	312	205	107	0.343
7	UK	312	195	117	0.375
8	Canada	286	204	82	0.287
9	Brazil	215	143	72	0.335
10	Denmark	209	121	88	0.421
11	Sweden	209	145	64	0.306
12	Switzerland	181	98	83	0.459
13	Netherlands	179	98	81	0.453
14	Australia	174	127	47	0.27
15	Portugal	159	113	46	0.289
16	Belgium	133	79	54	0.406
17	Iran	123	76	47	0.382
18	India	119	93	26	0.218

Figure 2. Percentage contributions of most productive nations

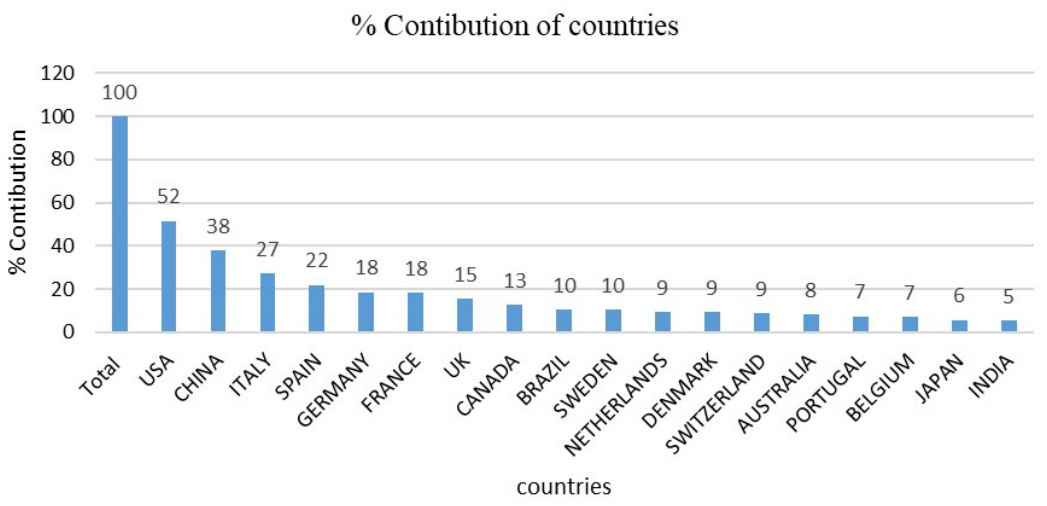
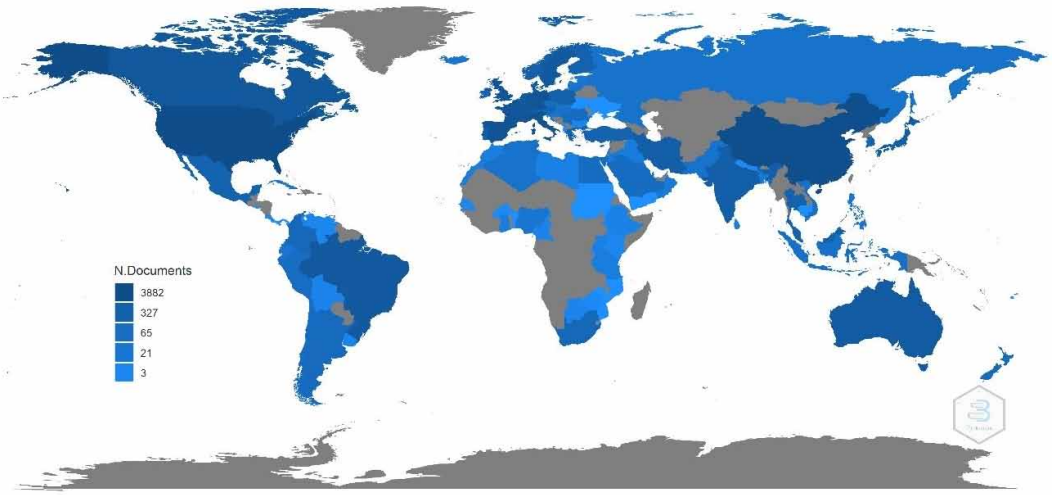


Figure 3. Research output from the nation



(USA, China, Germany, France, and Spain) in particular stand out for their close collaboration with one another. The intense link among nations suggests that governments are collaborating on LCA-related concerns. This partnership trend promotes the adoption and progress of LCA while also facilitating its adoption in a large number of Nations.

Statistics of Most Relevant Sources on LCA

In the topic of LCA, a record of 820 sources was retrieved. The critical aspects of the top 15 leading sources are shown in Table 6 and Table 7. According to the analysis, the Journal of Cleaner Production (1276) has the most publications, contributing to 16.96 percent overall, followed by the International Journal of Life Cycle Assessment (963, 12.80 percent) and the Sustainability (338, 4.49 percent). The most cited source in LCA is the Journal of Cleaner Production, which has the highest number of

Table 5. Most cited nations

Rank	Country	Total Citations (TC)	Average Article Citations (AAC)	% Contribution
1	USA	29508	27.94	16.05
2	Italy	16497	26.10	8.97
3	China	14915	19.17	8.11
4	Spain	13463	28.52	7.32
5	Germany	9957	25.93	5.42
6	UK	9343	29.95	5.08
7	Denmark	8655	41.41	4.71
8	France	7694	24.66	4.19
9	Canada	7274	25.43	3.96
10	Netherlands	6768	37.81	3.68
11	Switzerland	6531	36.08	3.55
12	Sweden	5049	24.16	2.75
13	Norway	4715	45.34	2.56
14	Brazil	4289	19.95	2.33
15	Belgium	3980	29.92	2.16
16	Australia	3876	22.28	2.11
17	Portugal	3245	20.41	1.77
18	Iran	2778	22.59	1.51
19	India	2315	19.45	1.26

citations in total (35720). The source impact of a journal is indicated by its g-index and h-index. The journal's influence grows in proportion to its indexes (g, h, and m). The Journal of Cleaner Production has got the highest indexes (79, 102, and 6.08), followed by the International Journal of LCA (72, 100, and 5.54) and Environmental Science & Technology (53, 89, and 4.08). (6.395). Moreover, the Sustainability journal has the third rank in source contribution, but its source impact rank is fifteen.

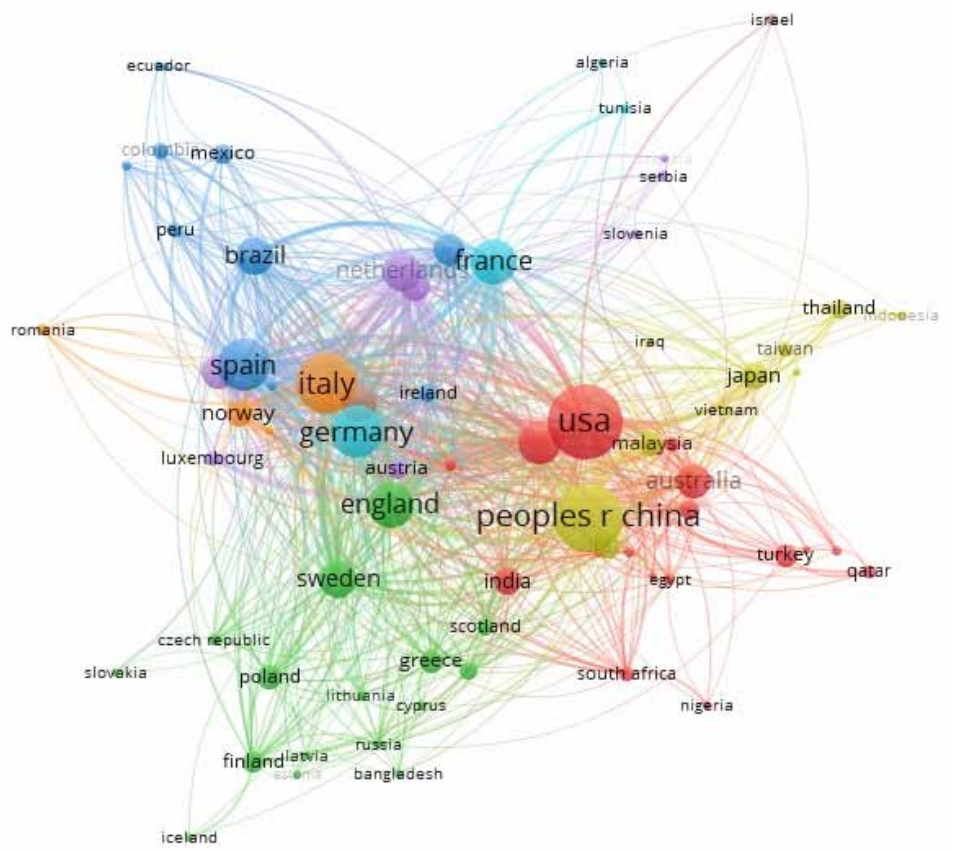
Figure 5 depicts the evolution of the five most important publication sources. Over the last decade, there has been a spike in publications. This spike could be attributed to new studies in the field of LCA. According to Fig. 5, the source growth of several journals (Journal of Cleaner Production, International Journal of LCA, Sustainability, and Journal of Industrial Ecology) has varied since 2010. Still, the Journal of Cleaner Production has had explosive growth in recent years. There has been a decrease in publication activities in the Journal of Industrial Ecology over the last year (2020-2011).

Statistics of Author Productivity on LCA

The amount of literature on the topic by the author demonstrates the extent and quality of its study. There was a record of 17069 authors across the 7522 publications. Table 8 shows that the top fifteen authors contributed more than thirty-four LCA articles. Wang Y from North Carolina State University has the most publications and the highest articles fractionalized (quantify an individual author contribution to a published set of papers), indicating a more significant impact in the subject of LCA.

In research, one indication is the "most cited paper" ranking, which reveals the most significant, investigated, and researched subjects. The frequency of citations for a paper demonstrates its scholarly significance. Widely cited publications demonstrate that this paper's scientific information has been

Figure 4. International scientific collaboration on LCA



recognized by many other researchers in the same area and has a substantial reference value. Table 9 lists the top author production summary with highly cited papers in LCA. The most cited article was published by Heijungs et al., 2011, entitled "Life Cycle Assessment: Past, Present, and Futures" with the TC 664, TC per Year 53.33, in "Environmental Science & Technology."

Statistics of Most Global Cited References

Analyzing what other people say about your work is a good way to add to the standard analysis. The foundation of any article is its references. Accordingly, by looking at cited references, we can get a better sense of which study papers are of most interest to researchers in a certain discipline as they organize and perform their studies. The top 10 leading frequently cited references are shown in Table 10. The most highly cited reference is published by ISO (2006; 14040, 14044) with the title of "Life Cycle Assessment-Principles and Framework" and "Life cycle assessment - Requirements and guidelines" in the ISO Standardization, with 1366, 1085 citations, respectively. These ISO standards are the backbone of the LCA studied. The third most cited reference is "Recent developments in life cycle assessment "by Finnveden et al., 2009 in the "Journal of environmental management," with 581 citations.

Trending Topic and Author Keywords

The author's study objective and expertise in a topic area are frequently reflected in the keywords. Researchers can discover scientific hotspots in the domain of LCA by looking at keyword occurrence and grouping. The co-occurrence visualization of author keywords is depicted in Figure 6. The diameter

Table 6. Source contribution

Rank	Sources	Articles	% Contribution
1	Journal of Cleaner Production	1276	16.96
2	International Journal of Life Cycle Assessment	963	12.80
3	Sustainability	338	4.49
4	Journal of Industrial Ecology	223	2.96
5	Science of The Total Environment	218	2.90
6	Environmental Science & Technology	200	2.66
7	Resources Conservation and Recycling	181	2.41
8	Energies	130	1.73
9	Applied Energy	123	1.64
10	Waste Management	117	1.56
11	Renewable & Sustainable Energy Reviews	108	1.44
12	Bioresource Technology	101	1.34
13	Energy	100	1.33
14	Journal of Environmental Management	95	1.26
15	Renewable Energy	83	1.10

Table 7. Source impact

Element	h_index	g_index	m_index	TC	NP	PY_start
Journal of Cleaner Production	79	102	6.08	35720	1207	2010
International Journal of Life Cycle Assessment	72	100	5.54	23296	864	2010
Environmental Science & Technology	53	89	4.08	9332	189	2010
Applied Energy	47	72	3.62	5916	119	2010
Renewable & Sustainable Energy Reviews	46	84	3.54	7177	103	2010
Resources Conservation and Recycling	43	68	3.31	6248	174	2010
Waste Management	40	66	3.08	4875	108	2010
Bioresource Technology	39	72	3.00	5494	97	2010
Journal of Industrial Ecology	39	64	3.00	5810	201	2010
Science Of The Total Environment	38	56	2.92	5021	210	2010
Building and Environment	33	59	2.54	3554	76	2010
Energy	32	49	2.46	2957	98	2010
Energy and Buildings	32	55	2.46	3126	65	2010
Journal of Environmental Management	30	47	2.31	2560	89	2010
Biomass & Bioenergy	29	48	2.23	2392	61	2010
Renewable Energy	27	45	2.08	2327	78	2010
Sustainability	25	39	2.08	2995	278	2011

Figure 5. Source dynamics

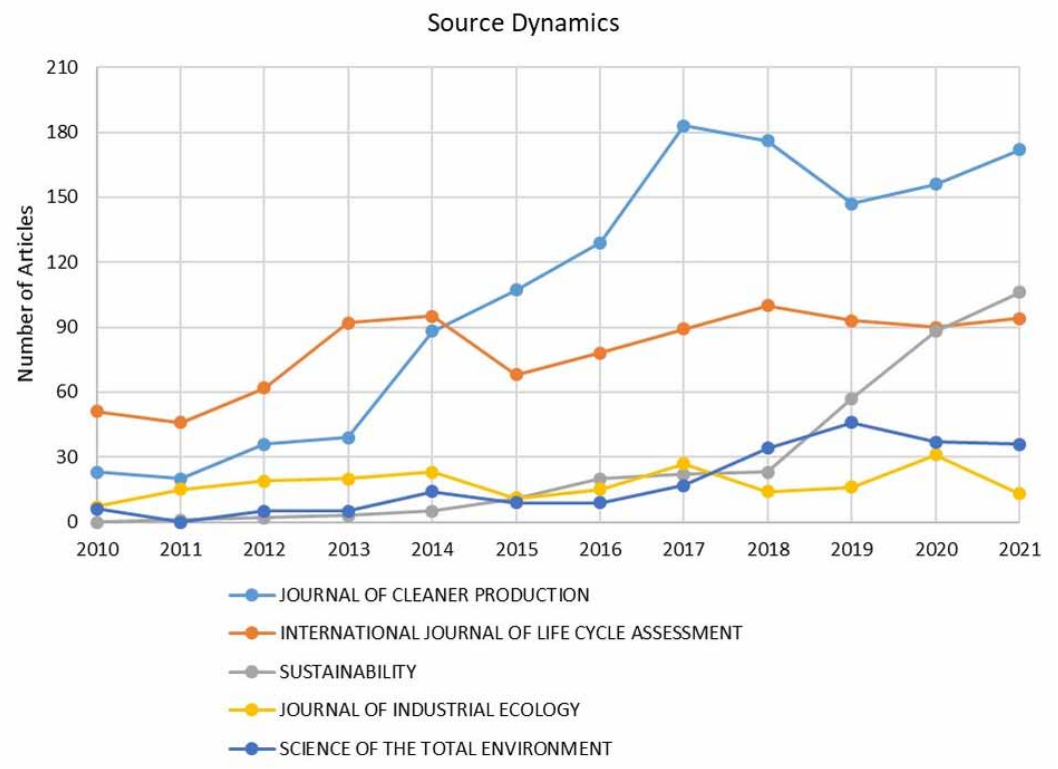


Table 8. Authors contribution in LCA

Rank	Authors	Articles	Articles Fractionalized
1	Wang Y	60	12.50
2	Li J	54	11.63
3	Zhang Y	50	12.39
4	Finkbeiner M	47	14.54
5	Heijungs R	43	16.44
6	Sala S	43	11.64
7	Vazquez-Rowe I	42	10.51
8	Feijoo G	41	8.85
9	Zhang X	40	8.98
10	Hong J	39	8.57
11	Gonzalez-Garcia S	37	7.98
12	Wang X	37	7.26
13	Sonnemann G	36	7.72
14	Li Y	34	5.96
15	Zhang H	34	7.42

Table 9. Top Author production summary

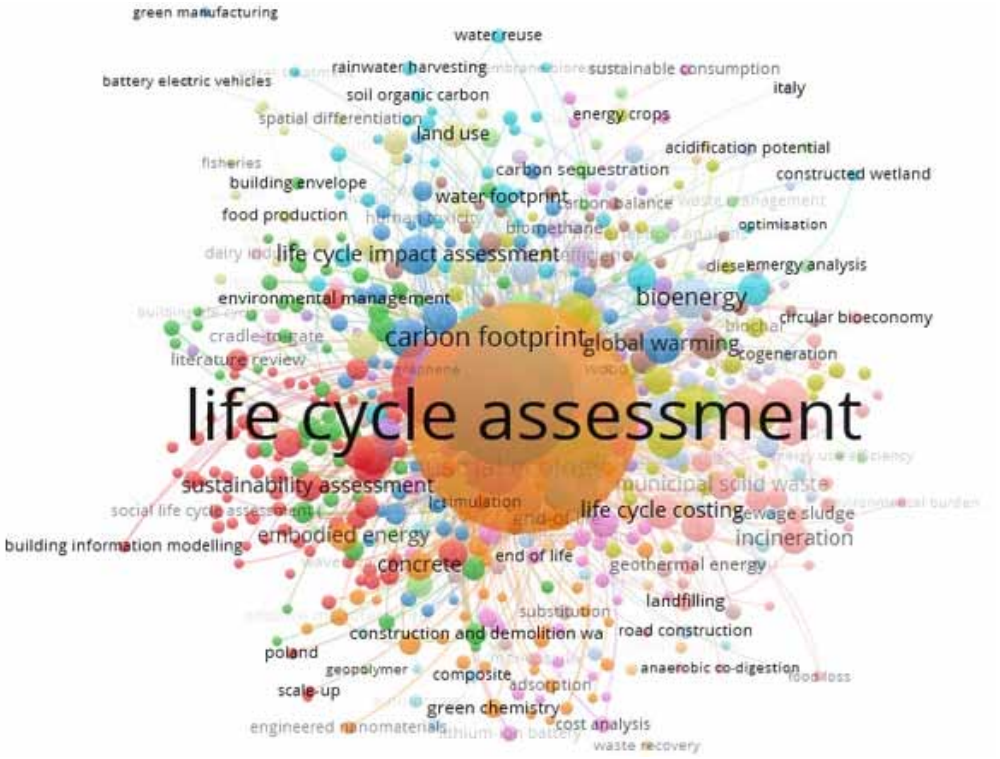
Rank	Author	Title	Source	DOI	TC	TC per Year
1	Guinee et al., 2011	Life Cycle Assessment: Past, Present, and Futures	Environmental Science & Technology	10.1021/es101316v	664	55.333
2	Yang et al., 2011	Life-Cycle Analysis on Biodiesel Production From Microalgae: Water Footprint And Nutrients Balance	Bioresource Technology	10.1016/j.biortech.2010.07.017	500	41.667
3	Levasseur et al., 2010	Considering Time In LCA: Dynamic LCA and its Application to Global Warming Impact Assessments	Environmental Science \& Technology	10.1021/es9030003	307	23.615
4	Patel et al., 2016	Techno-Economic and Life Cycle Assessment On Lignocellulosic Biomass Thermochemical Conversion Technologies: A Review	Renewable & Sustainable Energy Reviews	10.1016/j.rser.2015.09.070	234	33.429
5	Laurent et al., 2014	Review Of LCA Studies of Solid Waste Management Systems - Part Ii: Methodological Guidance For A Better Practice	Waste Management	10.1016/j.wasman.2013.12.004	229	25.444
6	Notarnicola et al., 2017	The Role of Life Cycle Assessment in Supporting Sustainable Agri-Food Systems: A Review of The Challenges	Journal of Cleaner Production	10.1016/j.jclepro.2016.06.071	226	37.667
7	Koellner et al., 2013	Unep-Setac Guideline on Global Land Use Impact Assessment on Biodiversity and Ecosystem Services In LCA	International Journal of Life Cycle Assessment	10.1007/s11367-013-0579-z	213	21.3
8	Sala et al., 2013	Life Cycle Sustainability Assessment in the Context of Sustainability Science Progress (Part 2)	International Journal of Life Cycle Assessment	10.1007/s11367-012-0509-5	189	18.9
9	Zamagni et al., 2012	Lights And Shadows In Consequential LCA	International Journal of Life Cycle Assessment	10.1007/s11367-012-0423-x	181	16.455
10	Heijungs et al., 2010	Life Cycle Assessment and Sustainability Analysis of Products, Materials, And Technologies. Toward A Scientific Framework For Sustainability Life Cycle Analysis	Polymer Degradation and Stability	10.1016/j.polymdegradstab.2009.11.010	178	13.692
11	Chen et al., 2017	Life Cycle Assessment of Greenhouse Gas Emissions and Water-Energy Optimization For Shale Gas Supply Chain Planning	Energy Conversion and Management	10.1016/j.enconman.2016.12.019	171	28.5
12	Li et al., 2010	An LCA-Based Environmental Impact Assessment Model For Construction Processes	Building and Environment	10.1016/j.buildenv.2009.08.010	164	12.615
13	Freire et al., 2013	Impact of The Electricity Mix and Use Profile in The Life-Cycle Assessment of Electric Vehicles	Renewable & Sustainable Energy Reviews	10.1016/j.rser.2013.03.063	162	16.2
14	Feng et al., 2014	The Energy And Water Nexus In Chinese Electricity Production: A Hybrid Life Cycle Analysis	Renewable & Sustainable Energy Reviews	10.1016/j.rser.2014.07.080	157	17.444
15	Boulay et al., 2011	Regional Characterization Of Freshwater Use In LCA: Modeling Direct Impacts On Human Health	Environmental Science & Technology	10.1021/es1030883	150	12.5

of the circle shows the keyword's occurrence. The bigger the circle, the more often it appears. The co-occurrence relationships among two terms are represented by the line connecting two circles. The colours circle on the map denote distinct clusters, and the cluster structure is determined by an interaction between the components, culminating in clusters of highly connected components. Seven thousand five

Table 10. Most global cited references

Rank	Cited References	Total Citations
1	ISO 14040, 2006	1696
2	ISO 14044, 2006	1645
3	Finnveden et al., 2009	581
4	Guinée et al., 2002	451
5	Wernet et al., 2016	448
6	Jolliet et al., 2003	418
7	Rosenbaum et al., 2008	314
8	Rebitzer et al., 2004	256
9	Guinee et al., 2011	250
10	Huijbregts et al., 2017	244
11	Reap et al., 2008	222

Figure 6. Co-occurrence visualization of author keywords



hundred twenty-two papers were discovered during the preceding ten years of publishing, with 10682 author keywords connected to LCA during the standard search. Environmental impact (461 frequency), Sustainability (442 frequency), Impact Assessment (369 frequency), Industrial Ecology (180 frequency), Environmental (167 frequency), Circular Economy (122 frequency), Bioenergy (112 frequency) were

the most frequently used author keywords in the LCA field. Most frequent author keywords reflect the trending topic in the LCA. Table 11 depicts the trending topic on LCA. Figure 7 illustrates a word cloud of the author keywords. The magnitude of words in the map indicates how frequently they occur.

Table 11. Trending topic on LCA

Trending Topic	Frequency	Start Year	Mean Year	Current Year
LCA	4006	2014	2017	2020
Environmental Impact	461	2015	2018	2020
Sustainability	442	2015	2018	2020
Impact Assessment	369	2015	2018	2020
Industrial Ecology	180	2013	2017	2019
Environmental	167	2016	2019	2020
Circular Economy	122	2019	2020	2021
Bioenergy	112	2014	2016	2020
Emissions	80	2014	2016	2020
Renewable Energy	79	2016	2019	2020
Environment	77	2014	2016	2020
Biofuel	74	2013	2016	2018
Biorefinery	67	2016	2019	2020
Social Life Cycle Assessment	61	2018	2019	2020
Environmental Assessment	55	2015	2019	2020
Techno-Economic Analysis	27	2018	2020	2020
Energy Storage	25	2020	2020	2021
S-LCA	25	2016	2020	2021
Bioeconomy	17	2020	2021	2021

Figure 7. Word cloud on LCA

CONCLUSION

LCA has proven to be beneficial for assessing environmental consequences and crucial for achieving sustainability. Because of the increasing worldwide changes in climate, numerous administrations and governmental organizations have made initiatives to alleviate greenhouse emissions, which generates the tremendous potential for the progress of LCA-related studies. However, there have been a lot of LCA studies undertaken on a variety of topics around the world. There's extremely little literature on this topic that undertakes bibliometric analysis. This study emphasizes this field by showing many elements such as the collection of publications written on LCA, their linguistic diversity, type of articles, top authors, journals, and nations publishing papers on LCA. Aside from that, the top 20 viral documents were presented and document co-citation of documents written in English over the last ten years. According to the data, English is the most commonly used language in publications, and most documents are articles. The pattern in scientific publications indicates that LCA research has exploded in popularity during the last few years. Even though the USA dominates LCA research globally, Native American nations are the world leaders in research output, with the most significant average production. Few journals, such as the International Journal of LCA, Journal of Cleaner Production, Environmental Science & Technology, and Journal of Industrial Ecology, have many LCA-related publications than the others. The primary goal of this research is to present the conceptual evolution of LCA as obtained through bibliometric analysis.

CONFLICT OF INTEREST

The authors of this publication declare there is no conflict of interest.

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