

Life Cycle Assessment (LCA) in Circular Economy Systems: A Bibliometric Literature Review

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Abstract The circular economy is a sustainable concept, whose objective is to maintain products, components and materials at their highest level of utility and value. This article conducts a bibliometric study on the topics; Circular Economy and Life Cycle Assessment, looking for publications that cover the topic and make a network map of the main authors cited through the evaluation of 327 publications. The research was carried out through bibliometric analysis in the Scopus database, from 2010 to 2019. The result of this work may contribute to new research in the area, since bibliometric analysis allows to create a list of the main publications based on building a network map.

Keywords: Life Cycle Assessment; Bibliometrics; Circular Economy; CE; LCA

1 Introduction

The circular economy is a concept born in the 70s, which presupposes the rupture of the linear economic model (extract, transform and discard), applied to the vast majority of companies. This new economy model describes a concept of returning value added to materials and products already in process, returning them to the production chain (MERLI, PREZIOSI, ACAMPORA, 2018).

In 2015, the G7 requested from the Organization for Economic Cooperation and Development (OECD) a guide to public policies to promote the efficient use of natural resources, and the following year the document Policy Guidance on Resource Efficiency was published, reinforcing the need for practices circular, aiming to reduce resource consumption, increase reuse and promote recycling (CNI, 2018).

From a socio-environmental perspective, sustainable development (SD) has gained notoriety in public and private institutions, as it constitutes an opportunity to consolidate or improve its position in society and in the market (BEVILACQUA et al., 2011; UN, 2019). In this context, government policies encourage SD through norms and regulations, as an example, the reduction of greenhouse gas emissions. Likewise, the development of circular economy systems, in addition to being a political and market trend, can increase revenue generation with a more efficient process and greater value for the aggregate product and also with loss reduction (EEA, 2017).

The sustainability approach has gained strength in recent years, as well as the number of tools developed for management and monitoring of DS (VARGAS et al., 2019). Among these tools, the life cycle assessment (LCA) stands out, which aims to analyse systems, be it a product, service or process, from the extraction of raw material through of the conception to its final disposal “from cradle to tomb ” (BEYLOT et al., 2020).

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LCA is carried out based on quantifiable indicators of environmental impact, such as energy use, heating, ozone depletion, acidification, eutrophication, air pollution, human and ecotoxic toxicity, formation, and generated waste (SHELDON, 2017).

The LCA process principle is to calculate the GHG emissions of each process in the product cycle individually, in order to form a chain of processes that covers the entire life cycle. Each process analysis is performed using primary data specific to the process (material and energy flows in the manufacturing process) and secondary data (GHG quantity) per manufacturing process, which lead to accurate results of modelling, this survey of data obtained by the LCA being the first step for companies, or chains of companies, to develop more sustainable operations in their processes (RISTIMÄKI et al., 2013).

Studies for environmental optimization of circular economy operations have been developed through the application of LCA in several sectors, for example, in the photovoltaic solar energy industry (HSUEH, LIN, 2014), of solvents (SZITA, 2017), of foods (NIERO, RIVERA, 2018) and many others.

According to Iritani et al. (2015), the recurrent scientific mapping of bibliometric analysis helps researchers to observe the structural network of a research area. The use of LCA in the circular economy is recent and has grown in recent years, so that a quantitative study, using bibliometric techniques, is necessary to analyse this field.

Bibliometric analysis is a useful method to identify research trends and hot issues based on historic publications information. It is also used to evaluate research performance of institutions, researchers and journals, as well as the research fields (LI, HAN, LU, 2018).

The use of the bibliometric method is important in the scientific context, considering that the number of publications increases continuously and that researchers gradually find it difficult to search for relevant literature in their field of study (LOISEAU et al., 2016). In this context, the elaboration of a theoretical framework through bibliometrics allows the researcher to carry out a quantitative analysis of the publications, finding relationships between the structural elements, such as: references, authors, keywords, among others (IRITANI et al., 2015).

Thus, the present work aims to identify the global characteristics of the literature associated with the theme circular economy and LCA, in order to present associations and trends that provide a basis for future work.

2 Methodology

The first phase of the research (Figure 1) was responsible for defining the sampling of the analysis, according to Ramos and Oliveira (2019).

Two of the most popular data sources for bibliometric studies are Clarivate Analytics' Web of Science (WoS) and Elsevier's Scopus (CORTÉS-SÁNCHEZ, 2020).

Scopus was selected for the following reasons: institutional access; highest magazine coverage (Scopus: 20,346 journals vs. WoS: 13,605 (149% more journals), overlapping coverage ($\approx 84\%$ of active securities in WoS were also indexed in Scopus) (CORTÉS-SÁNCHEZ, 2020).

Therefore, the choice of publications in this database justifies the tradition of the debate about knowledge and the degree of impact of its journals at the scientific and academic level, in addition to configuring it as a consolidated space that brings together scientific productions edited by different countries. in the world.

The search in the database covered the years 2010 to 2019. The search terms used were: (“life cycle assessment LCA”) AND (“circular economy”), where they were applied to the title, abstract and keywords fields in english language. A total of 327 publications were extracted.

For the second phase, with the sampling defined, all available metadata were imported, such as: abstract, authors, keywords, journal, references, number of citations, among other data. They were exported and later analysed using Microsoft Office Excel 2010 and Vos Viewer software. It was possible to extract the results sought in the work, such as: publications per year, journals with the largest number of publications, authors with the largest number of publications, most cited authors, institutions with the largest number of publications, countries with the largest number of publications, map of co -quotation and map of words co-occurrence (LEYDESDORFF, CARLEY, RAFOLS, 2013).

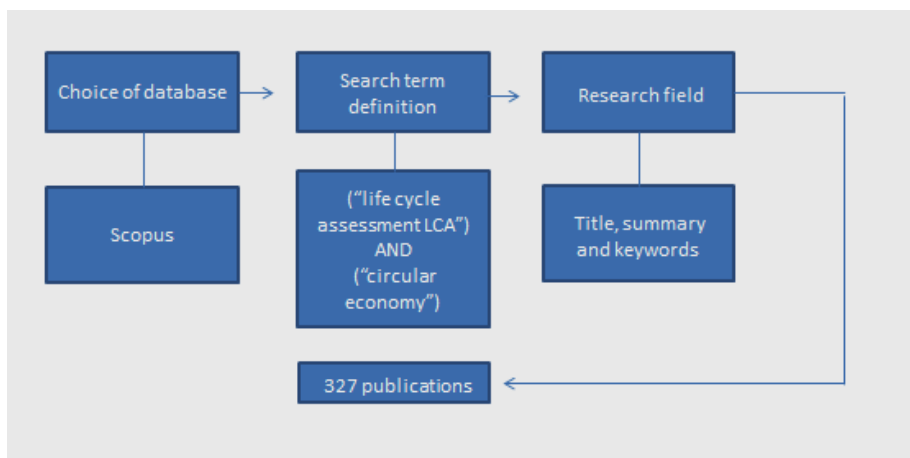


Fig 1: Phase 1 (sample definition). Adapted from Ramos e Oliveira (2019).

4 Results and discussion

Regarding the results of the survey with a sample of 327 publications, the first information extracted was the number of publications per year (Figure 2). It is observed that the number of publications remains without much fluctuation until 2014, and from then on growing, until reaching a number of 137 publications in 2019, showing that there is a trend line, resulting from a possible maturation of this field of research.

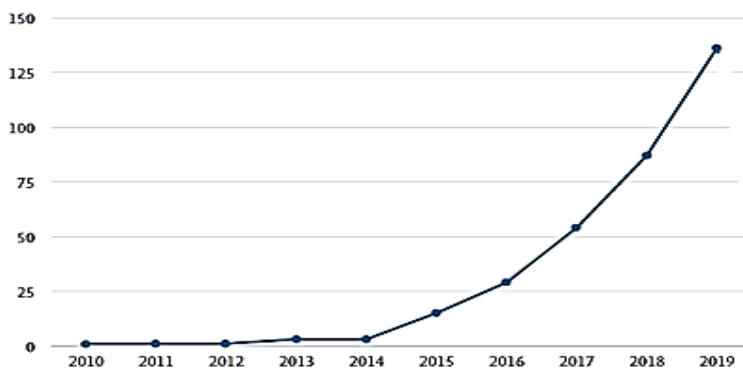


Fig 2: Number of publications per year. Source: SCOPUS (2019).

The publications found were classified by the SCOPUS database into 20 categories of different subjects, and there may be publications with more than one subject.

From the main categories, it can be seen that the works have a strong relationship with management and the environment and energy. Environmental Sciences are in first place for the articles under study; the subjects of Engineering and Energy are between the second.

314 journals were found of the different areas of knowledge. The top 10 journals in terms of quantity of publications are shown in Table 1, with more than 60% of the total sample. The journals *Journal of Cleaner Production* and *Resources Conservation And Recycling* have the greatest representativeness, with 53 and 39 publications respectively. In relation to the Impact Factor (IF) index, the *Resources Conservation And Recycling* period stands out, with the highest index in 2018.

Table 1: Analysis of the 10 main journals.

Nome do Journal	Number of Publications	%	IF - 2018	IF - last 5 years
Journal Of Cleaner Production	53	16,88	6,395	7,051
Resources Conservation And Recycling	39	12,42	7,044	6,562
Sustainability Switzerland	19	6,05	2,592	2,801
Procedia CIRP	17	5,41	2,100	1,345
Waste Management	12	3,82	5,431	5,993
Top Conference Series Earth And Environmental Science	11	3,5	0,44	0,23
Science Of The Total Environment	11	3,5	5,589	5,727
International Journal Of Life Cycle Assessment	9	2,87	4,868	5,524
Waste Management And Research	9	2,87	2,015	1,480
Bioresource Technology	8	2,55	6,669	6,589
Journal Of Industrial Ecology	8	2,55	4,826	4,039

The 327 publications were analysed according to their origin, geographic and institutional, resulting in 54 countries and 159 different institutions. With regard to countries, shown in Table 2, the top ten in terms of quantity of publications represent almost 75% of publications. Italy leads the list in relation to the number of publications (53), followed by Spain (49), the United Kingdom (40), Denmark (33) and Germany (31) all with a number of publications close by.

Table 2: Analysis of the top 10 countries.

Name of the country	Quantity Publications	% of articles
Italy	53	11,86
Spain	49	10,96
United Kingdom	40	8,95
Denmark	33	7,38
Germany	31	6,94
China	29	6,49
United States	28	6,26
Sweden	25	5,59

Netherlands	18	4,03
Canada	14	3,13

Due to the variety of institutions found in the sample, the majority with a low index of publications, it is inconclusive to cover the most representative portion of them. Given the above, only the seven main institutions were analysed in terms of quantity of publications, as shown in Table 3, of which it is possible to analyse that all institutions are located in one of the ten main countries, reinforcing the relevance of these countries on the topic under study.

Table 3: Analysis of the main institutions.

Institution Name	Quantity Publications
Danmarks Tekniske Universitet	20
University of Manchester	12
Universidad de Cantabria	11
Universitat Pompeu Fabra Barcelona	10
Aalborg Universitet	9
Universitat Autònoma de Barcelona	9
European Commission Joint Research Centre	9

Through a cocitation analysis, in which the authors cited by the 327 works in the sample, 1144 different authors were found. The analysis considers that when two authors are cited by the same article, they have a link and the set of these links form the chains of authors. Figure 3 shows the networks formed by the authors who were cited at least once within the sample, resulting in a total of 60 authors divided into 5 different streams, distinguished by colors. The main network, represented by the color red, has 22 authors and indicates that the connection strength between these authors is more intense than in the other currents. Regarding the relevance of the authors, the greater the circumference, the greater the number of citations.

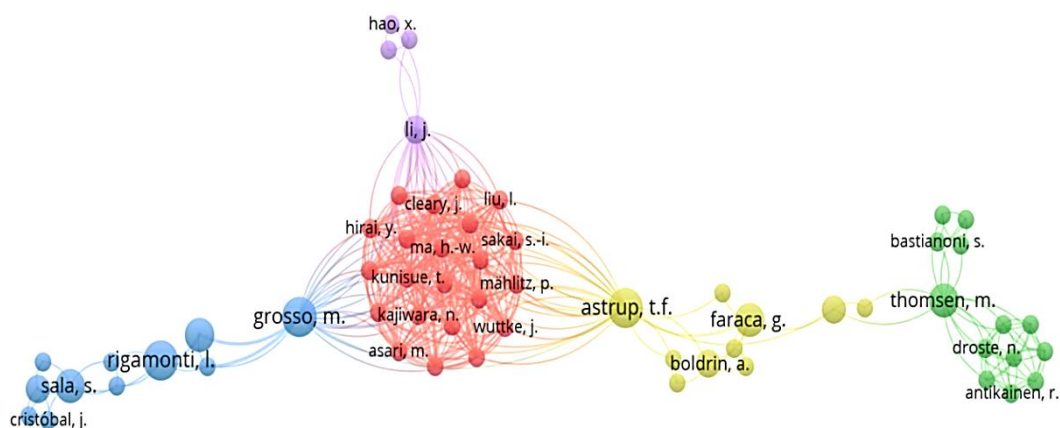


Fig 3: Network map of the main authors mentioned.

The map resource was used to analyse the content of the articles, considering the words that occur in the title, in binary count, in which the occurrence in the article is verified, regardless of frequency. 1066 different words were found. Figure 4 shows the map of words that occur in at least 50 articles, resulting in

887 words. This confirms that the publications address, in addition to LCA, issues of environmental impact and circular economy, such as waste, environmental assessment, material flow, among others.

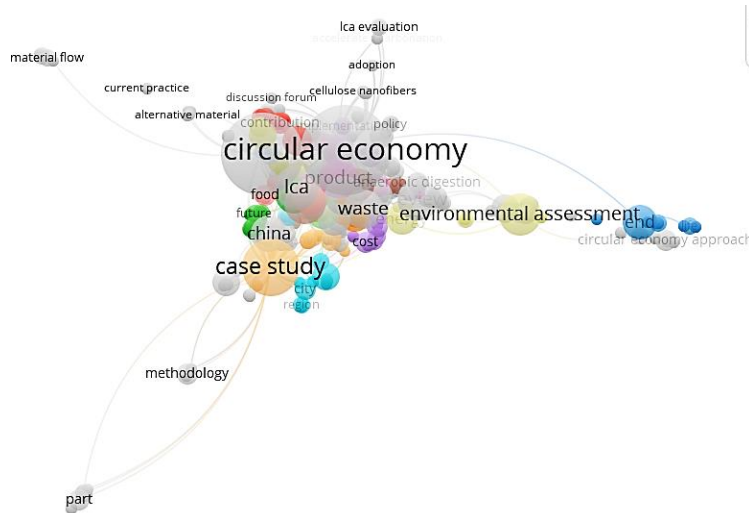


Fig 4: Map of words co-order.

Table 4 shows the main cited publications, including the average citation per year (CY), name of the journal and country of origin of the first author. European countries occupy the most relevant position, accounting for 80% of the most cited publications, followed by India and Arabia, with one publication each. With respect to publication sources, the *Journal of Cleaner Production* leads the list, occurring three times. The *Bioresource Technology* journal stands out with two articles. The most cited work was published by *Green Chemistry*.

Table 4: main cited publications.

Year	Number of citations	CY	Publication	Periodical	Country
2017	220	73	The E factor 25 years on: the rise of green chemistry and sustainability	Green Chemistry	Netherlands
2016	186	47	Waste biorefinery models towards sustainable circular bioeconomy: Critical review and future perspectives	Bioresource Technology	India
2017	109	36	Sewage sludge disposal strategies for sustainable development	Environmental Research	Poland
2017	93	31	Waste biorefineries: Enabling circular economies in developing countries	Bioresource Technology	Arabia
2017	86	29	Metrics of Green Chemistry and Sustainability: Past, Present and Future.	ACS Sustainable Chemistry & Engineering	Netherlands
2016	80	20	Two LCA based methods to analyse and design complex (regional) circular economy systems. Case: making water tourism more sustainable.	Journal of Cleaner Production	Netherlands
2016	76	19	Green Economy and related concepts: an overview	Journal of Cleaner Production	France
2018	69	35	How do scholars approach the Circular Economy? A systematic literature review	Journal of Cleaner Production	Italy

The first and fifth article discusses the use of metrics for sustainability, since its first conception in 1924, going through the changes that occurred until reaching the current concepts. The author also parallels the

use of LCA and the circular economy in the pharmaceutical industry. Finally, it concludes that both the use of LCA and the circular economy converge for the improvement of production processes with the construction of new eco-efficient designs, while for the reuse and recycling of products that would traditionally be discarded.

The second and the fourth works use the circular economy in waste bio-refinery. The authors discuss the environmental benefits produced by bio-refinery and LCA as an assessment tool for environmental impacts. For the authors, bio-refineries are highly energy efficient and mainly use production processes with zero waste and allow industries to manufacture ecological products with small carbon footprints.

Already in the third article the authors conduct a review and compare existing solutions for sewage sludge management in relation to environmental sustainability. The most commonly used strategies according to the authors include treatment and disposal. Decision-making tools were selected, as well as the life cycle assessment, were proposed to adequately assess the possible environmental, economic and technical assessment of different systems. Therefore, some basic criteria for the best selection of suitable options have been described, in the sense of the circular economy “from waste to resources”. The importance of sewage sludge as valuable source of matter and energy was appreciated, as well as a potential risk related to the application of these strategies.

The sixth article discusses complex business models that use environmental analysis metrics such as the LCA and the circular economy. According to the authors, LCA is currently the best-defined system for analysing environmental aspects and is capable of analysing circular systems, product service systems and systems for recycling. However, LCA falls short of analysing the added value of business models. Also according to the authors, the Eco-efficient Value Creation approach helps to avoid many pitfalls of the design of circular business models (for example, having a positive result at the product level, but with a negative effect on the social level; having a positive effect on the environment, but with insufficient perceived value from the customer to overcome the fierce market competition). The Circular Transition Framework reveals pitfalls and opportunities in implementation (for example, coordination between business models and government policies).

The seventh work makes a bibliometric review on the different concepts that encompass the green economy. According to the authors, their various links with sustainability are not always clear, and they use strength and weakness criteria to assess sustainability tools.

The eighth article performs a systematic review of the literature on Circular Economy. According to the authors starting from a studied concept in relation to industrial ecology, Circular Economy slowly acquired its independent role in academic research, mainly framed in studies related to environmental sustainability.

5 Conclusion

Bibliometric analyses were carried out based on a sample of 327 publications covering the theme of LCA applied to the circular economy and its activities, which allowed observing the growth in bibliometric terms. It is observed that the use of LCA as a tool to support environmental management is growing, both in terms of the number of publications and its relevance. The works were classified in 20 categories of different subjects, most of which are in the area of Environmental Science. The main periodicals found were: *Journal of Cleaner Production* and *Resources Conservation And Recycling*.

There are 15 authors who have the greatest influence in the literature, with Niero, M. being the main one. The country with the largest number of publications is Italy, while the most relevant institution is Danmarks Tekniske Universitet, in Denmark.

The result of this work may contribute to new research in the area of circular economy and LCA, since bibliometric analysis allows to draw a network map based on the construction of the theoretical framework.

This study provided a comparative analysis between countries which allows more comprehensive criteria for those with low production or impact on the association between circular economy and LCA.

With bibliometric analysis it is possible to locate influential researchers or organizations within different countries; thus identifying future research partnerships. It is also possible to identify which are the most influential journals in the national or international area.

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