LIFE CYCLE ASSESSMENT METHOD IN EDUCATIONAL INSTITUTIONS TOWARDS CIRCULAR ECONOMY: A SYSTEMATIC LITERATURE REVIEW AND BIBLIOMETRIC ANALYSIS

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ABSTRACT

This article presents a systematic review of the literature using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method associated with a bibliometric analysis of life cycle assessment (LCA) in Educational Institutions. OpenRefine and VOSviewer software supported bibliometric analysis. The scientific gap was identified by correlating the observed co-authorship interactions with countries and the co-occurrence with the keyword "author". A total of 22 papers were selected and categorized into five fields: Reference, Objective, Focus, Journal, and Key Findings. After reading the articles a total of 13 papers were included for meta-analysis and were selected into seven fields: Reference, Topic, Fields, Method, Integrated Method, Software, and Impacts. Considering the application of LCA in educational institutions from a Circular Economy perspective, the systematic literature review showed that there are few studies with the LCA in educational institutions especially in the waste management field. The studies are mostly focused on environmental science and the methodological basis of application is the LCA governed by ISO 14.040/14.044. The studies mostly use the Ecoinvent database and the OpenLCA software for data collection and calculation procedures. The most cited impact is the Global Warming Potential (GWP).

KEYWORDS: *Life Cycle Assessment; Educational Institution; Systematic Literature Review; Bibliometric Analysis.*

I. INTRODUCTION

Educational establishments exert influence not only on their immediate surroundings but also on their value chains, necessitating the adoption of a life cycle approach [1]. The Life Cycle Assessment (LCA) methodology has been developed by the UNEP/SETAC Life Cycle Initiative to expand the original scope of LCA for sustainability evaluation [2]. The International Organization for Standardization (ISO) has formulated a comprehensive LCA methodology through the ISO 14040 series, which was initially established in the 1990s. ISO 14040 was subsequently revised in 2006, and ISO 14044, which encompasses four stages of LCA application (goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation), was introduced [3] [4].

LCA is widely recognized by the European Commission and international literature as the most effective framework for quantifying the environmental impacts of various activities, products, and services [2]. In this regard, the implementation of LCA holds the potential to mitigate the environmental consequences stemming from waste management, an area that significantly affects public health, the environment, and the economy [5]. This is particularly crucial within educational institutions, given their direct influence on the local environment and value chains, thereby necessitating the adoption of a life cycle approach [6].

Previous documents addressing this subject primarily focused on studying environmental impacts in engineering fields, utilizing multi-criteria approaches that were limited to the assessment of raw material and energy consumption, air and water pollution, and waste generation. These studies primarily emphasized energy efficiency, raw material consumption, and the final disposal of waste [7]. However, more recent articles have aimed to encompass the entire life cycle of a product, process, or activity, including stages such as raw material extraction and processing, transformation, transportation, distribution, use, reuse, maintenance, recycling, and final disposal. These concepts are well-established in the ISO 14040 series of standards [8].

Life cycle assessment (LCA) is conducted to analyze indicators pertaining to specific products or processes [9]. While there are numerous articles applying LCA, they predominantly focus on the engineering field, particularly civil construction, as this sector significantly contributes to natural resource consumption and solid waste generation. The application of LCA in educational institutions is important due to their role as crucial sources of knowledge and promoters of innovative concepts. Educational institutions have the potential to enhance knowledge, culture, human values, and progress [10]. However, there is a scarcity of LCA applications in the service sector, specifically within Higher Education Institutions, particularly in the domain of waste management. This scarcity prompted the authors to conduct a systematic literature review on this subject [11].

The literature indicates a growing interest in the relationship between the Circular Economy (CE) and life cycle assessment (LCA), with a particularly close connection to waste management [12]. The circular economy aims to eliminate pollution and waste generation while preserving the product's integrity over multiple use cycles. LCA can support the circular economy by facilitating actions such as reducing energy consumption throughout the product's life cycle, minimizing greenhouse gas emissions, promoting recycling, purchasing products with recyclable components, and encouraging furniture reuse. Educational institutions, including universities, play a crucial role in supporting the transition to a more circular economy through their contributions to education, research, and leadership [13].

Despite the increasing connection between educational institutions and LCA, there is currently limited integration between the concepts of LCA and the circular economy within these institutions. However, the application of LCA can have a positive impact on the circular economy within educational institutions. By employing LCA, educational institutions can transform into "green" campuses [14] by calculating greenhouse gas emissions, assessing carbon footprints [15], and evaluating social impacts such as human health, discrimination [16], and transparency [17].

Therefore, the objective of this study is to examine the existing literature on the implementation of Life Cycle Assessment (LCA) in educational institutions, specifically regarding waste management. Recognizing that the proper application of the LCA method is intricate and time-consuming, the authors acknowledge that many studies conducted in educational institutions have not been effectively concluded. The outcomes of LCA applications in educational institutions have been compiled to identify best practices and provide guidance for future research in this field. It is worth noting the broad scope of these findings, as they encompass not only environmental benefits, which are the primary focus of LCA but also the financial and social aspects, as demonstrated in various studies where the LCA method has been effectively employed within educational institutions.

The structure of this article is as follows: the research methodology is portrayed by defining Qualitative Analysis via PRISMA Method and Quantitative Analysis via Bibliometric Review. This is followed by Results and a Discussion of the findings. Finally, the article concludes by highlighting the findings, contributions, limitations and further research suggestions.

II. Materials and Methods

In order to enhance the effectiveness of identifying and acknowledging scholarly output pertaining to Life Cycle Assessment (LCA) in Educational Institutions, a systematic review of the literature was conducted in conjunction with bibliometric analysis. This methodological approach was inspired by the work of [18], which advocates for the combined utilization of these two methodologies as a means to comprehensively demonstrate the progression of scientific research. The bibliometric analysis offers a quantitative assessment of the evolution of scientific studies, while the systematic review facilitates a qualitative examination of the subject matter and content through in-depth investigations.

2.1. Qualitative Analysis via PRISMA Method

Given the substantive nature of the subject matter addressed in this article, a systematic literature review becomes imperative to collect pertinent studies focusing on a specific issue, accompanied by objective summaries of the produced findings. As outlined by [19], a systematic literature review involves the systematic identification and selection of relevant research, the extraction of data, and the analysis of observed results within the scientific domain.

This study employed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol to conduct the review, ensuring the inclusion of essential aspects such as literature search, selection of eligible published papers, data extraction, and summarization.

For the purpose of bibliographic research, the Scopus database was utilized, considering a time frame of five years. The focus was on worldwide open access documents from indexed journals. Scopus was selected due to its reputation for consistency, standardization, and credibility in academic research.

The search strategy and terms were performed using the advanced mode, considering previous expert comments and knowledge of the research unit, externalized through the search string: TITLE-ABS-KEY((("life cycle analys*" and "LCA") or ("life cycle assessment" and "LCA")) and ((education* and institution*) or (universit*) or (high* and education*))).

A total of 726 documents were found using the search string cited above. Data were then exported with a complete record and cited references and saved in tabular format for further analysis in Microsoft Excel, developing graphs and tables.

The research conducted by [18] indicates that OpenRefine 3.5.1 software is recommended due to its compatibility with various data manipulation tasks and its effectiveness in data cleansing, resolving ambiguous information, eliminating redundancies, and facilitating data format transformations.

2.2. Quantitative Analysis via Bibliometric Review

In accordance with the findings of [18], bibliometrics encompasses a range of quantitative, statistical, and mathematical techniques employed to examine and construct indicators pertaining to the patterns and developments within the scientific domain. Specifically, these methods concentrate on investigating disciplines, areas of study, organizations, or countries.

The data utilized for bibliometric analyses are typically sourced from prominent article databases dedicated to academic journals and magazines [20].

The data analysis in this study was conducted using the methodology outlined in [18]. To facilitate the construction and visualization of bibliometric maps, the researchers utilized the VOSviewer software. This software, freely accessible, offers a comprehensive and user-friendly approach to building and interpreting bibliometric maps. As elucidated in [5], these maps are represented by circles that represent individual items, with the size of each circle reflecting the significance of the respective element. The connections between items in the network map indicate the proximity of their relationships. Additionally, the position and color of the circles are employed to cluster similar elements [21].

This paper considered two bibliometric indicators to perform this study: co-authorship with countries as unit analysis and co-occurrence with author keyword as unit analysis.

As outlined in [21], the indicator "co-authorship with countries as unit" refers to the relationship between items based on the number of co-authors involved in papers, with a specific focus on highlighting the countries of the respective authors. This indicator examines the collaborative nature of research across different countries. On the other hand, the indicator "co-occurrence with author keywords as unit" pertains to the relationship between papers based on the frequency of occurrence of shared keywords among them. This indicator emphasizes the commonality of specific keywords used by authors in their publications, providing insights into thematic similarities and research trends. Both indicators offer valuable perspectives for understanding research collaboration and thematic connections within the studied dataset.

III. RESULTS

3.1. Overview of publications on LCA in educational institutions

3.1.1. Chronological analysis of publications

According to the used string cited before 726 documents were found that refer to the LCA in educational institutions. Figure 1 quantifies the chronological contribution of the published articles on LCA, specifically for educational institutions and universities. As can be seen in Figure 1, the average number of publications has increased over the years and one can notice three jumps in publications: in the year 2005, between the years 2010-2014, and between the years 2017 and 2018. The years with the most publications are 2013 and 2018, with 76 and 50 papers, respectively.

It can be explained by the holding of major conferences around the world or incentive programs for sustainable projects within universities. The first leap in 2005 can be explained by the 2002 World Summit on Sustainable Development in Johannesburg [9], which emphasized the importance of establishing a comprehensive set of programs centered on sustainable consumption and production and in 2005 the Kyoto Protocol [22] came into force, ratified by 192 countries. The second publication jump in 2010 may be a consequence of the launch of the UI GreenMetric World University Ranking. The last leap, in 2017, may have consequences of the adoption of the 17 Sustainable Development Goals in September 2015 [9] and the holding of the 2015 Climate Change Conference in Paris [23], which states that immediate action must be taken to protect natural and environmental resources by reducing GHG emissions.

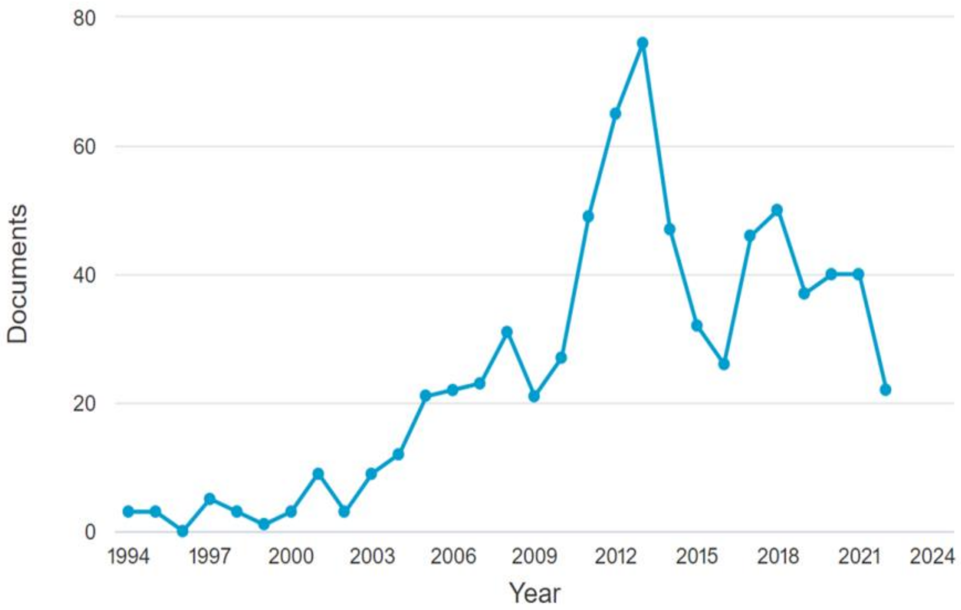

Figure 1. Number of documents published per year.

3.1.2. Analysis of publications by country

As can be seen in Figure 2 the country that contributes the most documents is the United States with 195, followed by Italy (71), Germany (60), China (58) and Spain (51). The visualization map (Figure 3) created based on bibliographic data chosen in VOSviewer software, can explain the amount of published documents per country. The present study employed an analytical approach to investigate co-authorship patterns, focusing on the country unit. The analysis utilized bibliographic CSV database files, which were processed using the full counting method. A maximum of 25 countries were considered in each document, ensuring a minimum threshold of ten documents per country. Remarkably, 100 countries successfully met this criterion, allowing for robust analysis. Moreover, the study assessed the overall strength of co-authorship connections between each of the 24 selected countries and other nations. This examination of country co-authorship serves as a valuable unit of analysis and provides insights into the cumulative link strength. The United States (Total link strength: 60) has close links with Brazil, the United Kingdom, Norway and Sweden. Italy (Total link strength: 37) has strong links with Germany, Spain, the Netherlands and France. China (Total link strength: 29) has a strong link with Australia.

One of the reasons why the U.S. appears with a considerable amount of publications is because of the "green" initiatives of many HEIs (Institutions of Higher Education) and focused commitments such as the prominent American College & University Presidents Climate Commitment (ACUPCC) [22], which is a network of colleges and universities committed to reducing greenhouse gas emissions. The publications from European countries (Italy, Germany and Spain) may be a consequence of the European Green Deal, established in 2019, which has goals for European countries of considerable reduction in energy consumption by 2030 and zero net greenhouse gas emissions by 2050. The competition for the achievement of the reduction target in energy consumption set by 2030 may account for the publication rate among these European countries. [21]. Regarding the Asian country with the highest number of publications (China), it can be explained by the fact that the university student population has increased considerably in the last 20 years [24].

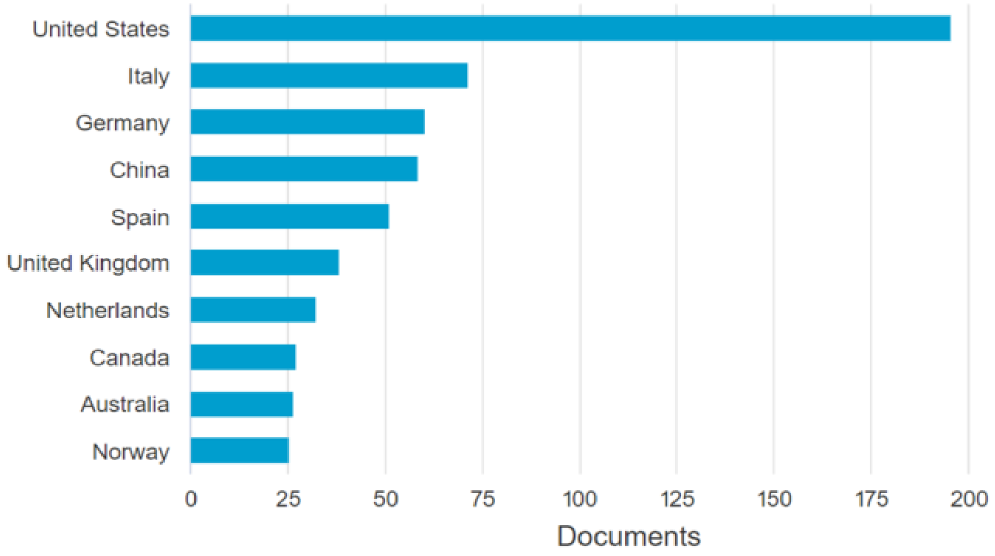

Figure 2. Number of documents per country.

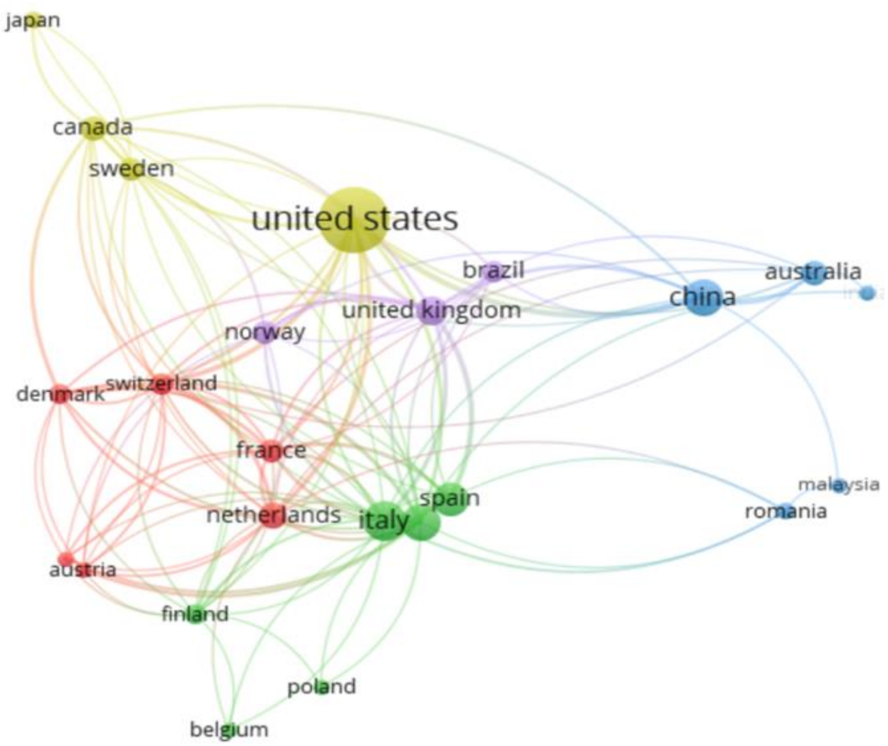

Figure 3. Co-authorship countries.

3.1.3. General analysis of the publication's keywords

The study employed the VOSviewer software to generate an overlay visualization map (Figure 4) using bibliographic data selected through co-occurrence analysis. The analysis encompassed all Author's keywords, and the data were sourced from CSV bibliographic database files, subjected to the full counting method. The criterion for keyword selection was a minimum occurrence of five, and the full counting method was applied accordingly. Subsequently, the study calculated the cumulative strength of co-occurrence links between each of the 1845 keywords and other keywords. From this analysis, the 70 keywords with the highest total link strength were identified and subjected to further examination. As can be seen, the keywords were separated into twelve clusters named according to the most occurring keyword, as shown in Table 1. Based on the VOSviewer software analyzed in Figure 4, there were 23 keywords across 5 occurrences. Moreover, the most used keyword is "Life Cycle Assessment (LCA)" with 345 searches, and the total link strength was 465, followed by "Industrial Ecology" with 146 searches and a total link strength of 268. "Environmental Impact" occurred 76 times with a total link strength of 137. The distance between the keywords is proportional to the relationship between them. The keyword "Life Cycle Assessment (LCA)" is very close to "Industrial Ecology", indicating that these concepts possibly originate from each other. The keywords "teaching", "higher education" and "engineering education" are relatively close to the term "sustainability", but "recycling" and "food waste" are more distant. This is because no studies were found that relate LCA to waste management issues in educational institutions.

Analyzing the concepts over time, it can be seen that the documents related to teaching ("higher education", "university", "education", "Teaching") are more recent (>2018) and increase the number of publications. This also happens with the documents that talk about social and organizational aspects ("organizational life cycle assessment" and "social organizational LCA") of LCA that also appear more recently (>2020) and have been gaining strength in quantity. In summary, it can be observed in figure x that the studies focused on the development of LCA, mainly for calculating the carbon footprint, following the stages of life cycle inventory (LCI) and life cycle impact assessment (environmental, social, and financial). Currently, there is a trend of studies on the development of LCA in educational institutions, especially because of the UI Green Metric World University Ranking, American College & University Presidents Climate Commitment, and conferences like the Climate Change Conference in Paris and the European Green Deal. The focus is on organizational and social life cycle assessment as well as on topics such as circular economy, although this keyword is far from "higher education", indicating a need for in-depth research to apply circular economy in the education sector. The studies in the area of waste management are not recent, but they are closely related to the circular economy, which would be an opportunity to apply in educational institutions.

Table 1. Author keyword occurrences.

Author's Keywords	Clusters	N. of Occurrence
Industrial Ecology	1	146
Sustainability	2	45
Life Cycle Analysis	3	32
Environmental impact	4	76
Life Cycle Assessment (LCA)	5	345
Meta-Analysis	6	11
Climate Change	7	10
Impact Assessment	8	10
Energy Analysis	9	5
Cost-benefit Analysis	10	5
Green buildings	11	5
Wastewater	12	6

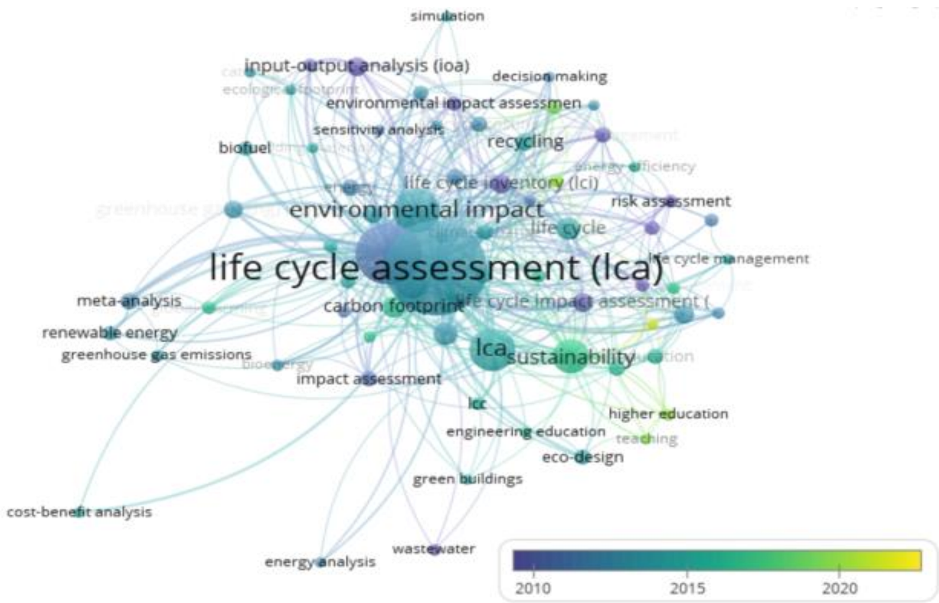

Figure 4. Author keyword overlay visualization.

3.1.4. Journal Impact Factor (JIF) indicator

The analysis conducted in this study utilized the VOSviewer software to examine the cited resource unit using the full counting method. The threshold for inclusion required a minimum of 20 citations for each cited reference. Out of the total 1689 cited references, only 14 references met this criterion. Interestingly, three of these references shared the same name, indicating potential overlaps or duplications. For each of the remaining eleven cited references, the study calculated the overall strength of co-citation links with other cited references, enabling a comprehensive understanding of their interconnections. Table 2 shows that the cited references with the greatest total link strength were "j. Clean. Prod." A source with 183 citations, which was the highest among publications of LCA in educational institutions. The second source refers to "Int. Life Cycle assess.", with 127 citations. The third source of publication is “Sustainability”, with 76 citations. The other sources such as "energy build", "build environ.", "Energy", "Sol Energy", "renew. sustain. energy rev", "appl. Energy" and "resour. conserv. Recycl." appear with 42, 34, 28, 26, 22 and 21 citations respectively.

Table 2 also shows the Journal Impact Factor (JIF) indicator. As can be seen, the "renew. sustain. energy rev" has the highest impact factor, with 16.799; the second source with the highest impact factor is the "resour. conserv. Recycl.", with 13.716 and the third source is the "appl. Energy", with 11.446. The "J. Clean. Prod." has 11.072 impact factor; the "Energy" has 8.857. The other sources such as "energy build", "Sol Energy", "build environ.", "Int. Life Cycle assess." and "Sustainability" appear with 7.201, 7.188, 7.093, 5.257 and 3.889 JIF, respectively.

Table 2. Journal Impact Factor (JIF) indicator.

Journal	Citations	JIF
J. Clean. Prod.	183	11.072
Int. J. Life Cycle Assess.	127	5.257
Sustainability	76	3.889
Energy Build	42	7.201
Build Environ.	34	7.093
Energy	28	8.857
Sol. Energy	28	7.188
Renew Sustain. Energy	26	16.799
Appl. Energy	22	11.446
Resour. Conserv. Recycl	21	13.716

3.2. Systematic Literature Review: PRISMA Method

Figure 5 provides the PRISMA flow diagram for the records included in the review based on four steps of the search strategy (identification, screening, eligibility and included. From 726 documents screened from the Scopus database, 189 were selected, after discarding 537 due to refinement criteria in the screening stage (considering the published year < 5 years). Then, sixty-one were selected after reading the title (discarding titles without terms such as "higher education", "education", "classroom", "campus" and "university"). From these documents and after reading the abstract, twenty-two were included in the meta-analysis.

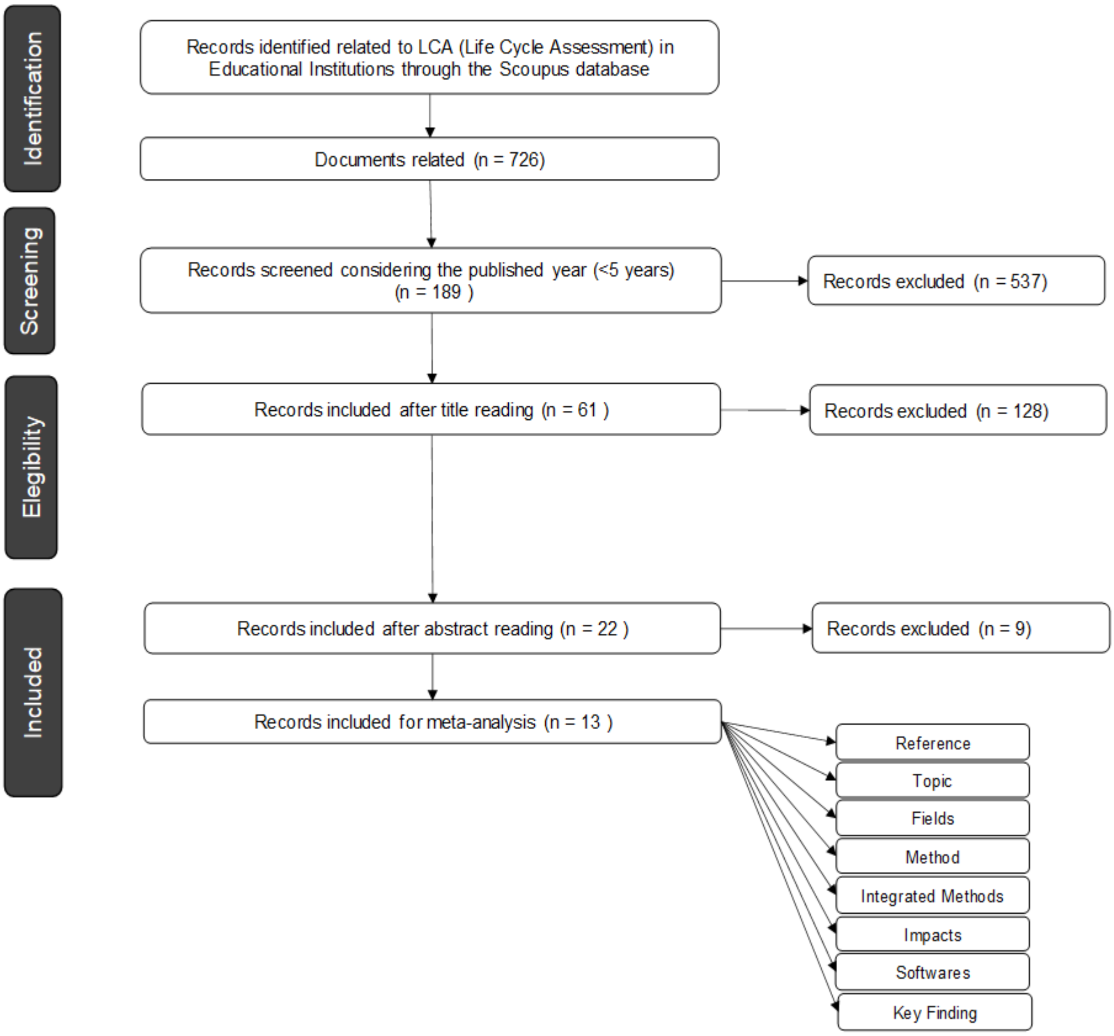

Figure 5. PRISMA flow diagram for the records selection process.

As mentioned before, after applying all filters such as the time lapse between 2018 and 2022 and reading the title, 22 documents were selected. After reading the abstracts of these documents, it was realized that, despite being related to the topic of LCA in educational institutions, some of them had a pedagogical approach to teaching LCA in educational institutions or were about a systematic literature review. The data information regarding all 22 documents was organized in Table 3, which shows the literature found about LCA in educational institutions. The data information has been divided into four topics: Reference, Topic, Focus and Journal.

Table 3. Literature review table on LCA in educational institutions (Source: Scopus).

#	Objective, Journal and Focus	Key Findings
[27]	Objective: to evaluate the Life Cycle of a Historic and Modern School Building Focus: LCA application Journal: Sustainability	The environmental impact of the modern school is significantly higher compared to the historical one despite the latter's high operational impact caused by energy consumption.
[29]	Objective: to calculate the organizational environmental and social footprint of a higher education institution. Focus: LCA application Journal: J. Clean. Prod.	Recommendation of improvements that can reduce the environmental and social impacts of the UPV/EHU activity.
[30]	Objective: to estimate the social footprint of a higher education institution and its potential contribution to Sustainable Development Goals under the LCA perspective Focus: LCA application Journal: Int. J. Life Cycle Assess.	Labor activity is the most significant sub-process within the social footprint, followed by transportation-related sub-processes
[11]	Objective: to integrate LCA and CBA methods to identify the effect that the inclusion of environmental impacts can have on decision-making in public procurement Focus: LCA application Journal: Sustainability	Low-carbon alternatives in seismic retrofit activities play an important role in mitigating environmental impacts in areas of high seismic activity.
[15]	Objective: to compare the carbon footprint of two transportation modes in campus transit, bus and bike-share systems, sing LCA. Focus: LCA application Journal: Sustainability	An alternative hybrid transit system reaches the most environmentally friendly state when 70% of passenger miles are provided by campus bus and 30% by the bike-share system.
[16]	Objective: to establish a life cycle assessment–life cycle cost (LCA–LCC) integrated model Focus: LCA application Journal: Sustainability	Environmental impacts and economic costs during the construction phase come mainly from the building material production process. Over the life cycle, the abiotic depletion potential of fossil fuels and the global warming potential are the most prominent index.
[31]	Objective: to demonstrate a project sustainability assessment framework that assesses not only the carbon footprint and life cycle cost of the project but also the external effect on the local community from a disaster resilience perspective. Focus: LCA application Journal: Sustainability	Green campus initiatives can reduce the carbon footprint of a university and improve the disaster resilience of the local community.
[32]	Objective: to evaluate university dormitories in terms of life cycle environmental impact and cost, as part of the sustainable development of university campuses. Focus: LCA application Journal: J. Clean. Prod.	a) The use stage is the dominant part of the life cycle environmental impacts and cost; b) The consumption of electricity constitutes the main element causing the environmental impacts over the life cycle; c) The window, concrete, steel, and cement have the largest contribution to the embodied environmental impacts but with the relatively small contribution to the life cycle cost.
[33]	Objective: to present a pragmatic framework to score and inform about the environmental sustainability and nutritional profile of canteen meals. Focus: LCA application Journal: J. Clean. Prod.	The presented framework shows a better characterization of environmental impact and covers the various sustainability aspects through its four parts, feedback to all stakeholders and its easiness of application for a manifold of meals.

[28]	Objective: to identify the potential social impacts that affect social well-being in the organization and analyze the correlation of social impacts from the beginning until the end of the cycle in the teaching and learning process. Focus: LCA application Journal: Int. J. Life Cycle Assess.	This study demonstrated a positive impact on their students' well-being although impacts such as discrimination and stress need to be reviewed and improved.
[34]	Objective: to evaluate the carbon footprint of higher education institutions using a streamlined life cycle assessment approach. Focus: LCA application Journal: J. Clean. Prod.	The largest sources of greenhouse gas emissions were electricity generation (41%), automotive commuting (18%), and steam generation (16%).
[2]	Objective: to assess the impacts of food consumption and wastage, including the nutritional characteristics. Focus: LCA application Journal: J. Clean. Prod.	The highest environmental contribution occurred at the food procurement stage (85%) and the largest costs are associated with food preparation activities and food purchases (39% meal cost). The embedded food waste impact accounts for 40 and 57% of the total global warming potential and about 27% of the total cost.
[14]	Objective: to conduct a detailed life cycle assessment of a University's buildings in a tropical climate Focus: LCA application Journal: J. Clean. Prod.	Suggestions to building professionals on ways to reduce the share of building embodied energy.
[24]	Objective: to publish a pedagogical experience with teaching life cycle assessment (LCA) in higher education. Focus: Pedagogical approach Journal: Sustainability	No records of regular courses for architecture and urbanism undergraduates were found and an online calculator was developed to allow expanded design experimentations in future editions.
[35]	Objective: to develop pedagogical approaches to apply in construction degrees. Focus: Pedagogical approach Journal: Sustainability	Using tools such as problem-based learning or research-based learning, and environmental tools, such as the life cycle assessment and computational thinking they acquire a sustainable approach to work "soft-skills" competencies into sustainability.
[36]	Objective: to assess and highlight trends in LCA learning outcomes. Focus: Pedagogical approach Journal: Sustainability	Presentation of the five levels of learning and competence: study program integration, workload, cognitive domain categories, learning outcomes, and envisioned professional skills.
[12]	Objective: to develop a Balanced Scorecard strategy map for implementing and monitoring environmental education programs in universities. Focus: Pedagogical approach Journal: J. Clean. Prod.	A theoretical proposal that can serve as a guide to implement and monitor environmental education programs in universities.
[25]	Objective: to describe and discuss 20 years of experience in teaching LCA at the MSc level in engineering. Focus: Pedagogical approach Journal: Int. J. Life Cycle Assess.	Historical evolution and statistics about the course and the benefits and challenges such as the theory acquisition, the assignment work, the LCA software learning, the conduct of case studies, the merits of industrial collaborations and grading approaches.
[37]	Objective: to identify the challenges of applying simplified LCA tools to improve the eco-efficiency of products and achieve a higher level of sustainable innovation Focus: Pedagogical approach Journal: Sustainability	The positive potential of applying the tools to achieve function innovation in design for sustainable innovation.

[9]	Objective: describes an Experiential Workshop for university undergraduates in which the Service-Learning pedagogic approach is taken and Flourishing Business Canvas is applied as a tool for collaborative visual business modeling.	Education for Flourishing is a useful expansion of Education for Sustainable Development
	Focus: Pedagogical approach	
	Journal: J. Clean. Prod.	
[8]	Objective: to perform a systematic review and bibliometric analysis of the OLCSA in the University.	Adoption of the LCSA framework is recommended for O-LCSA studies to estimate organizations' sustainability, and to ensure quality education contributing to the fourth SDGs.
	Focus: Systematic Review	
	Journal: Sustainability	
[26]	Objective: to present the trends in research on the carbon footprint of higher education	To show a state-of-the-art review of this area of research, specifically identifying the most productive sources, organizations, regions and research directions in the last ten years, and the network of sources, authors, references and keywords that connect various aspects of this productivity.
	Focus: Systematic Review	
	Journal: J. Clean. Prod.	

As can be seen, 59% of the articles presented a case study with the application of the LCA method in educational institutions, which will be detailed later. 32% of the articles addressed issues such as teaching experience and its importance for training future architects [12], pedagogical approach for sustainable development in construction for higher education [25], and teaching LCA in higher education [37], being the areas essentially engineering and architecture and urbanism. In the research two articles presented a systematic literature review focusing on social organizational life cycle assessment in educational institutions [9] and trends in research on the carbon footprint of higher education [26].

Considering the objective of this work, it was removed from these articles and used only the thirteen articles that effectively presented a case study of LCA application in an educational institution. For the meta-analysis, the data information regarding these documents was organized in Table 4, which shows the literature found specifically on LCA application cases in educational institutions. The data information has been divided into seven topics: Reference, Topic, Fields, Method, Integrated Method, Software and Impacts.

Table 4: Main characteristics and results from the sixteen articles selected (Source: Scopus)

References and Fields	Method/Others Methods/Software	Impacts
[27]	Method: EN 15978:2011 - Sustainability of Construction Works—Assessment of Environmental Performance of Buildings–Calculation Method.	Climate change; Fossil Fuel Consumption; Acidification Potential; HH Particulate; Ozone Depletion Potential; Smog Potential; Eutrophication Potential; Total Primary Energy and Non-Renewable Primary Energy
	Other Methods: EN European Standards regarding Sustainability of construction works	
Field: Engineering	Software: Athena impact	
[29]	Method: Social Impacts Weighting Methods	Terrestrial ecotoxicity, Ozone layer depletion, Climate change, Photochemical oxidation, Acidification potential, Eutrophication, Marine aquatic ecotoxicity, Depletion of abiotic resources - fossil fuels, Human toxicity, Depletion of abiotic resources - elements ultimate reserves,
	Other Methods: CML and ReCiPe Endpoint	
Field: Social Science	Software: OpenLCA (ecoinvent v3.3 and PSILCA-based Soca v1 add-on	

		Freshwater aquatic ecotoxicity, Human Health, Resources, Ecosystems
[30]	Method: Social Impacts Weighting Methods	Child labor, Forced labor, Fair salary, Working time, Discrimination, Health and safety, Social benefits, legal issues, Worker's right, Access to material resources, Respect for indigenous rights, Contribution to economic development
	Other Methods: -	
Research Area: Social Science	Software: OpenLCA (ecoinvent v3.3 and PSILCA-based Soca v1 add-on	
[11]	Method: Cba and LCA ISO14.040/14.044	climate change, FPMF, stratospheric ozone depletion, ionizing radiation, ozone formation, human toxicity (carcinogenic and on-carcinogenic), and water consumption.
	Other Methods: BIM, ReCiPe midpoint, MCDM	
Field: Engineering Science	Software: SimaPro v8.5.2 ecoinvent v3.4	
[15]	Method: LCA ISO14.040	Fossil depletion, Climate Change
	Other Methods: -	
Field: Environmental Science	Software: none	
[16]	Method: ISO14040/44 and ISO 15686-5	global warming potential, photochemical oxidant creation potential; acidification potential; eutrophication potential; abiotic depletion-fossil fuel potential.
	Other Methods: AHP/ social WTP/ MCDA/LCC	
Field: Engineering	Software: GaBi 8.7.1.30 Professional+Extension database	
[31]	Method: LCA ISO14.040/14.044	global warming potential (GWP)
	Other Methods: Life cycle energy assessment (LCEA)	
Field: Environmental Science	Software: OpenLCA v1.7 Ecoinvent v3.4	
[32]	Method: LCA ISO14.040/14.044	Climate change, Ozone depletion, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Human Toxicity, Photochemical oxidant formation, Particulate matter formation, Terrestrial ecotoxicity, Freshwater ecotoxicity
	Other Methods: ReCiPe Midpoint (H) V1.1	
Field: Engineering	Software: none	
[33]	Method: LCA ISO14.040/14.044	global warming potential (GWP)
	Other Methods: ReCiPe 1.12	
Field: Environmental Science	Software: Simapro version 8.0.5	
[28]	Method: LCA ISO14.040/14.044	students' health and safety, discrimination, feedback, privacy, transparency, and end-of-life responsibility which is a further plan
	Other Methods: SO-LCA (The Social Hotspots Database)	
Field: Social Science	Software: none	
[34]	Method: consumption-based hybrid LCA (HLCA) approach	global warming potential (GWP)
	Other Methods: -	
Field: Environmental Science	Software: openLCA 1.7 Ecoinvent database version 3.3	
[2]	Method: LCA ISO14.040/14.044	global warming potential, photochemical ozone
	Other Methods: LCC	
Field: Environmental Science	Software: none	

		creation potential, acidification potential, and eutrophication potential
[14]	Method: LCA ISO14.040/14.044	Energy
	Other methods: Building Information Modelling (BIM)	
Field: Engineering	Software: none	

IV. Discussion

4.1. The Role of Circular Economy in the LCA Scenario Based on a bibliometric study

Figure 6 shows specifically the relationships of the clusters based on the concept of Circular Economy. The circular economy is related to the concept of "life cycle assessment" and there is a close relationship with the concept of "recycling", "waste management" and "food waste". This is because the Circular economy (CE) aims to eliminate the concept of pollution and waste generation and maintain the integrity of the product over several use cycles [24]. Another aspect to be considered is that Figure 6 shows a recent growing interest in the relationship between these technologies.

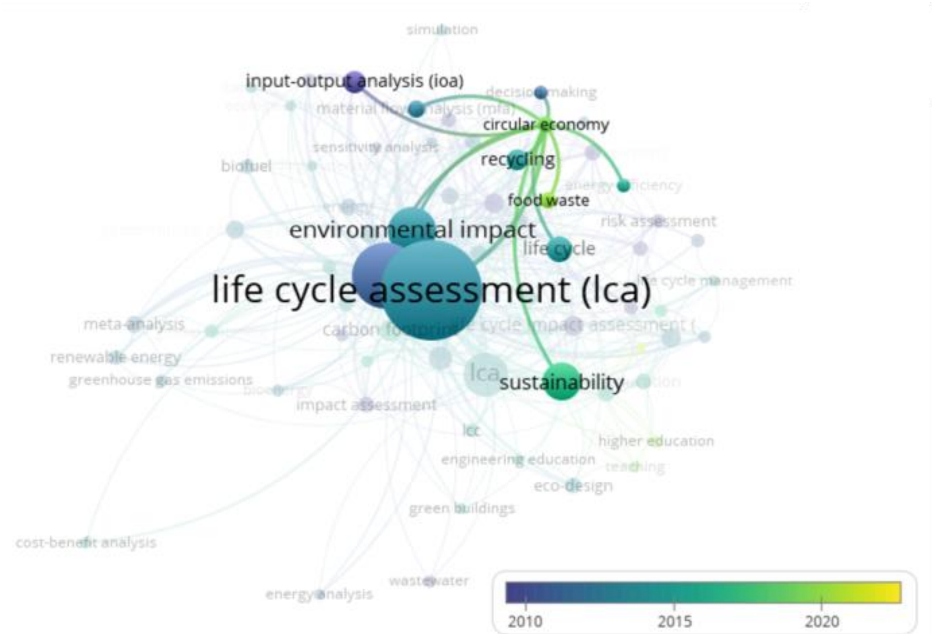

Figure 6. Author's keyword overlay visualization with circular economy focus.

The LCA concept can support the circular economy through actions such as reducing life cycle energy consumption, greenhouse gas emissions, recycling, buying products with recyclable content, and reusing furniture. This can happen through universities, which have an important role to play in helping support the transition to a more circular economy, including educational, research, and leadership aspects [6].

Although there is a growing recent interest in the relationship between educational institutions and the LCA, there is relatively little interaction between the concepts of LCA and circular economy within educational institutions. Figure 7 shows the interaction of the clusters related to the LCA in educational institutions and "circular economy" and "recycling". A distant and disconnected relationship is perceived.

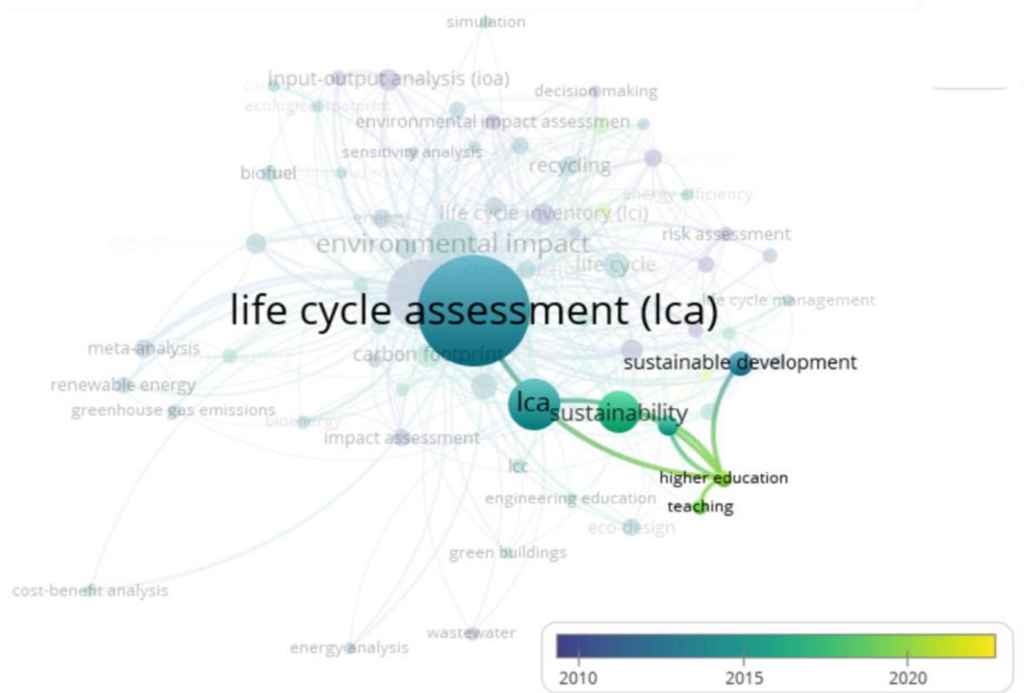

Figure 7. Author keyword overlay visualization with a higher education focus.

The studies presented showed that the LCA concept can contribute positively to the circular economy in educational institutions. Thus, through the LCA, educational institutions can become "green" campuses [14] since it is possible through this technology to measure the environmental impact of university buildings and propose actions such as insulation solutions in their structures that allow the reduction of energy consumption [27] since electricity consumption is one of the main elements that cause environmental impacts throughout the life cycle of their buildings [24]. In a study developed by [15], through the calculation of Greenhouse Gas emissions and Carbon Footprint, universities may propose hybrid transportation and the use of bicycles for internal locomotion and consequent reduction of environmental impacts. Other studies, besides environmental assessment, have also focused on the social impacts of educational institutions, evaluating indicators such as human health, discrimination [16] and transparency [28].

The methodology employed in this study, which is the Life Cycle Assessment (LCA), is recognized as a prominent environmental practice and has proven to be a suitable tool for evaluating environmental implications [24]. The LCA framework involves a comprehensive observation and analysis of the entire life cycle of a product or activity, aiming to quantify its environmental impact. It follows the ISO 14040/14044 series of international standards, which provide guidelines for conducting LCA studies [8] [26]. In this particular study, it was found that nearly 70% of the analyzed documents utilized the methodological framework of LCA governed by the ISO standards. This indicates the widespread adoption and acceptance of LCA as a robust approach for assessing environmental impacts in the field under investigation. Furthermore, an expansion of the LCA framework known as the Social Impacts Weighting Methods was employed in this study. This extension allows for the assessment of social impacts associated with products, services, and organizations [11]. By incorporating social factors into the analysis, researchers can gain a more holistic understanding of the overall sustainability and societal implications of the subject matter. Overall, the combination of LCA and Social Impacts Weighting Methods provides a comprehensive framework for evaluating both environmental and social aspects, facilitating a more complete assessment of the subject being studied.

The ISO 14.040/14.044 method generally follows four phases. In the initial stage of a Life Cycle Assessment (LCA), the primary focus lies in defining the study's objectives, specifying the boundaries of the system under investigation, and selecting the appropriate database for data collection [8]. Furthermore, it is imperative to establish clear and compatible objectives and scope that align with the intended application of the assessment [26]. Subsequently, the inventory analysis phase constitutes the second stage of the LCA methodology, wherein data collection and calculation procedures are employed to quantify the pertinent inputs and outputs of a product system [8]. This phase involves systematically gathering information on the resources utilized and the emissions and waste generated throughout the life cycle of the product or activity under scrutiny. The Ecoinvent database appeared in almost 70% of the studied documents and is considered an academically reputed LCA database [14] for use in this phase. The PSILCA (Product Social Impact Life Cycle Assessment) database is used for almost 15,000 industrial sectors and commodities in 189 countries and covers the social indicators [16]. For the calculations, 31% of the educational institutions analyzed used OpenLCA software, which has a free version. But 38%, did not use any software for calculation. Other important software that could be used to calculate the LCA was also identified in the study, such as SimaPro and GABI, but they have their paid versions. The next phase is the impact assessment. The Global Warming Potential (GWP) impact appears in more than 75% of the documents. And other impacts such as Acidification Potential (AP), Eutrophication Potential (EP), Photochemical Oxidant Creation Potential (POFP), and Stratospheric Ozone Depletion (ODP). Fossil Fuels Potential (FFP), Human Health and Human Toxicity Potential (HTP) were also frequently used by educational institutions for evaluating the potential environmental impacts. The final phase of a Life Cycle Assessment (LCA) is the interpretation stage, which aims to present the findings of the assessment in alignment with the predetermined goals and scope of the study. This phase involves analyzing and synthesizing the collected data and indicators to derive meaningful insights and conclusions. [8].

These impacts are directly related to the concept of Circular Economy since they involve three dimensions: environment, economy and society. Although 46% of the studies focus essentially on the field of Environmental Science, there is also some social and financial concern in these studies. The studies essentially worked on calculating the carbon footprint and transforming educational institutions into a "green campus". But the papers aim beyond reducing the carbon footprint, there are studies that suggest a hybrid form of internal transportation between bike sharing and the bus system within an educational campus [28] and the implementation of a solar photovoltaic system for electrical self-sufficiency [14], examples that involve environmental, social and financial issues. The 23% of papers focused on Social Sciences also considered social impacts that are generated by educational institutions such as Human Health and discrimination or indicators that are indirectly co-responsible for educational institutions such as child labor [11].

Although the studies involve all three dimensions, there is a gap in the application of LCA in educational institutions in the area of waste management and there is a great opportunity for study as it can involve and contribute to improvement in all three dimensions. The [eating out] study showed that food waste can represent up to 40 to 57% of the total global warming potential and about 27% of the total cost. Especially in Brazil, where waste management has a strong social character [10], the application of LCA in this area, within educational institutions, would play a full role in the circular economy, i.e. financial, environmental and social aspects. Moreover, these studies can contribute greatly to meeting the goals and targets set in major global conferences, such as the Paris Climate Change Conference and the European Green Deal.

V. CONCLUSIONS

The authors considered the 726 documents found after applying the search string. Data were then exported with complete records and cited references and saved in tabular format for further analysis in Microsoft Excel, developing graphs and tables. After that, the data were treated in OpenRefine 3.5.1, and to be able to interpret the data, the VOSviewer software was used to make possible the bibliometric analysis of the data.

Through bibliometric analysis, the articles were analyzed considering publications by country and the co-occurrence of the authors' keywords. The results show that the USA had the largest number of published articles. Italy, Germany, China and Spain also have a number of publications considered on this topic. For co-authorship between countries, the United States had the highest number of articles published in partnership with countries such as Brazil, the United Kingdom, Norway, and Sweden. Another close relationship was found between Italy and Germany, Spain, the Netherlands and France. China showed a strong link with Australia. One of the reasons why the U.S. appears with a considerable amount of publications is because of the "green" initiatives of many HEIs (Institutions of Higher Education) and focused commitments such as the prominent American College & University Presidents Climate Commitment (ACUPCC) [22], which is a network of colleges and universities committed to reducing greenhouse gas emissions. The publications from European countries (Italy, Germany and Spain) may be a consequence of the European Green Deal, established in 2019, which has goals for European countries of considerable reduction in energy consumption by 2030 and zero net greenhouse gas emissions by 2050. The competition for the achievement of the reduction target in energy consumption set by 2030 may account for the publication rate among these European countries. [23]. Regarding the Asian country with the highest number of publications (China), it can be explained by the fact that the university student population has increased considerably in the last 20 years [24].

About the co-occurrence data of the authors' keywords, the result showed that the most used keyword is "Life Cycle Assessment (LCA)", followed by "Industrial Ecology" and the "Environmental Impact". Analyzing the concepts over time, it can be seen that the documents related to education ("higher education", "university", "education", "Teaching") are more recent (>2018) and increase the number of publications. This is also true for the documents that talk about social and organizational aspects ("organizational life cycle assessment" and "organizational social LCA") of LCA that also appear more recently (>2020) and have been gaining strength in quantity.

Currently, there is a trend of studies on the development of LCA in educational institutions, especially because of the UI Green Metric World University Ranking, American College & University Presidents Climate Commitment, and conferences like the Climate Change Conference in Paris and the European Green Deal. The focus is on organizational and social life cycle assessment as well as on topics such as circular economy, although this keyword is far from "higher education", indicating a need for in-depth research to apply circular economy in the education sector.

After a bibliometric analysis, the authors performed the systematic literature review through PRISMA showing the relationship between LCA and the Educational Institution. A total of 22 papers were selected and categorized into five fields: Reference, Objective, Focus, Journal and Key Findings. The papers were divided into LCA application, pedagogical approach and literature review. After that, a total of 13 papers using the LCA application were included for meta-analysis and were selected into seven fields: Reference, Topic, Fields, Method, Integrated Method, Software and Impacts. Thus, by analyzing information such as References, Topics, Fields, Methods, Other Methods, Software and Impacts, it was possible to verify the scope of the articles studied. Considering the application of LCA in educational institutions from a Circular Economy perspective, the systematic literature review confirmed a limitation of the research.

The studies are mostly focused on environmental science and the methodological basis of application is the LCA governed by ISO 14.040/14.044. For data collection and calculation procedures, the studies mostly use the Ecoinvent database and the most used software is OpenLCA. The most cited impact in the studies presented in the educational institutions regarding the application of LCA is the Global Warming Potential (GWP).

As can be seen in the literature review there are few studies with the application of LCA in educational institutions in the waste management field. It is hoped that the information obtained from this paper can facilitate future applications of the LCA method in educational institutions.

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