Bibliometric Research on Sustainability Education

Tri Kurnia Fatmawati, Irwanto Irwanto

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Abstract

This research seeks to advance sustainability education by emphasizing green chemistry teaching, with the objective of reducing environmental impacts and promoting eco-friendly practices across various educational levels. The outcomes of this study include enhancing students' environmental awareness and practical competencies, such as waste reduction and the use of safer chemicals. The research employs project-based approaches and laboratory experiments to foster environmental sensitivity among students. To evaluate progress, pre-test and post-test assessments are used to measure improvements in their understanding of sustainability. Green chemistry education plays a pivotal role in mitigating pollution by instilling environmentally responsible principles in chemical processes. Bibliometric analysis is utilized to identify global trends in sustainability education, supporting the formulation of policies aligned with the Sustainable Development Goals (SDGs). The implications of this study provide a scientific basis for policymakers to design sustainable educational frameworks that integrate green chemistry principles. These frameworks aim to reduce environmental impacts while enhancing students' environmental awareness and practical skills. The emphasis on sustainability education is anticipated to equip future generations with the tools necessary to address environmental challenges. The analysis highlights the critical role of teacher training in ensuring the effective integration of green chemistry concepts into teaching practices. Moreover, the findings support policymakers in developing effective strategies for incorporating sustainability into education, fostering interdisciplinary collaboration, and contributing to global efforts toward achieving the SDGs. The bibliometric analysis in this study is based on data from 4,489 documents published between 1991 and 2024, revealing an average annual growth rate of 20.98%. This analysis identifies major research trends, keywords, and collaborative networks among authors and institutions, emphasizing the importance of international collaboration.

Introduction

This bibliometric study on "sustainability and education" utilizes data spanning from 1991 to 2024. During this period, 4,489 documents were published across 1,318 distinct sources, including journals and books. The average annual growth rate of these publications is 20.98%, reflecting a significant increase in interest in the

topic over the years. This trend highlights meaningful progress in the development of sustainability and education as a research domain.

The documents in the study have an average age of 5.17 years, with each receiving an average of 18.02 citations. The study cites a total of 204,319 unique sources, reflecting a broad and comprehensive literature base. In terms of content, 5,280 additional keywords (Keywords Plus, ID) and 10,151 author-assigned keywords (Author's Keywords, DE) were identified. These keywords are essential for identifying key research topics and emerging trends in the field of "sustainability and education."

The research involved 12,218 authors, with 661 of them contributing documents independently. A total of 714 publications were authored by a single individual. The data indicates a notable level of collaboration among researchers, with an average of 3.33 authors per publication. Additionally, 22.72% of the documents involved international collaboration, reflecting significant global involvement in sustainability and education research.

Through this data, bibliometric analysis provides valuable insights into the development of research in this field, identifying leading authors, collaboration networks, emerging trends, and overall publication patterns. Through this information, bibliometric analysis offers valuable insights into the evolution of research in this domain, identifying prominent authors, collaboration networks, and emerging trends, as well as the overall patterns of publication within the field.

Bibliometric Analysis

The bibliometric analysis spans over three decades, from 1991 to 2024, offering a broad perspective on the development of research in sustainability and education. This extensive time frame provides valuable insights into the trends and evolution of these fields. With 1,318 sources, including journals, books, and other materials, the diversity of publications contributes to a comprehensive understanding of the subject, ensuring a wide range of perspectives and disciplines are represented. The total of 4,489 documents analyzed reflects the growing interest in sustainability and education, highlighting a significant volume of research. The annual growth rate of 20.98% indicates a robust expansion of research activity, with an increasing number of researchers contributing to the field each year. The average age of documents is relatively young at 5.17 years, suggesting that recent publications are abundant and the topic remains dynamic and relevant. The high average citation count of 18.02 per document emphasizes the substantial impact these works have had on the academic community, with frequent references by other researchers. A total of 204,319 references demonstrates the extensive literature base that underpins these studies, lending credibility and support to the findings. Additionally, the analysis of keywords, with 5,280 author keywords and 10,151 additional keywords, shows a rich diversity of themes and subthemes explored, offering valuable insights into the varied research foci. The 22.72% international collaboration rate underscores the importance of cross-border cooperation, enriching the research methodology and perspectives. In conclusion, the bibliometric data presents a thorough overview of research in sustainability and education, highlighting trends, impacts, and collaborative efforts. This ongoing development and international collaboration indicate that sustainability in education is becoming an increasingly vital and

globally relevant topic.

Table 1. Main Information of Bibliometric Data

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1991:2024
Sources (Journals, Books, etc)	1318
Documents	4489
Annual Growth Rate %	20.98
Document Average Age	5.17
Average citations per doc	18.02
References	204319
DOCUMENT CONTENTS	
Keywords Plus (ID)	5280
Author's Keywords (DE)	10151
AUTHORS	
Authors	12218
Authors of single-authored docs	661
AUTHORS COLLABORATION	
Single-authored docs	714
Co-Authors per Doc	3.33
International co-authorships %	22.72

Method

The analysis of the bibliometric data reveals several significant trends in the field of sustainability and education. The total number of documents (4,489) reflects a substantial volume of research, indicating a growing interest in exploring this topic among researchers. The annual growth rate of 20.98% further emphasizes the increasing attention the field is receiving within the academic community, positioning sustainability in education as a major research focus. The involvement of 12,218 authors highlights the extensive collaboration in this area, illustrating the interdisciplinary nature of the research. A key contributor to this field is Leal Filho W, with 51 published documents, showcasing his leadership and influence in sustainability and education research. The diversity of sources (1,318) ensures a comprehensive analysis, drawing from a wide range of perspectives and methodologies. The journal *Sustainability (Switzerland)*, with 784 publications, is the most productive source, reflecting its significant role and impact in the academic community. The most cited article (DOI: 10.1016/j.jclepro.2014.09.048) demonstrates a notable influence, as it is widely referenced, suggesting it presents crucial findings or methodologies. The United States stands out with the highest number of publications (1,971), positioning it as a leading country in sustainability and education research. The University of Otago, with 75 documents, is identified as the top institution, indicating a strong focus on sustainability research. Popular keywords such as "higher education," "sustainability," "sustainable

development," "student," and "university sector" underline the central themes in this field, emphasizing the significant role of higher education in advancing sustainability goals. In conclusion, the bibliometric analysis provides a comprehensive overview of the research landscape in sustainability and education, highlighting substantial growth, widespread collaboration, and the continued relevance of the topic on a global scale.

Results

Publication Trends

The provided figure illustrates the annual scientific production related to the topic of "sustainability" and publication trends. The provided image displays the annual scientific output related to the topic of "sustainability and education" from 1991 to 2024. This graph shows the number of articles published each year, illustrating the increasing research trends in this field. In the early period, from 1991 to around 2005, the number of articles published annually was relatively low and stable, with little or no significant increase. However, starting in 2006, There was a steady increase in the number of publications, indicating a growing interest and awareness of the importance of sustainability in education. A more significant surge became evident around 2013, with a sharp rise in the number of articles published. This trend continued, reaching its peak in 2021, when the number of published articles approached 600 per year. Although there was a slight decline in 2022, the number of publications remained high compared to previous years.

Overall, this graph demonstrates that the topic of "sustainability and education" has gained increasing attention from the scientific community, particularly in the last decade. The sharp increase in scientific publications reflects a growing global awareness of the importance of integrating sustainability concepts into education, as well as intensified research efforts to develop sustainable approaches and practices in the educational context.

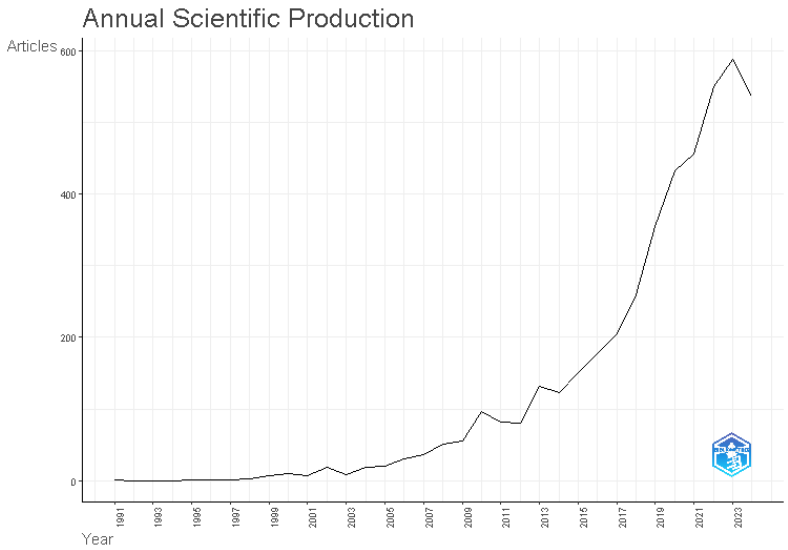

Figure 1. Annual Scientific Production of Sustainability

The image demonstrates the average number of citations per year for articles related to the topic. of "sustainability and education" from 1991 to 2024. This graph provides an overview of how frequently these

articles were cited by other research each year, reflecting the influence and relevance of studies in this field. In the early period of the study, the average citations per year were relatively high in 1991, but then experienced a sharp decline, reaching the lowest point around 1997. This decrease could be attributed to the limited number of publications and the initial lack of attention to the topic.

Starting from 1998, the average citations per year began to rise again, indicating increased recognition and impact of articles published on sustainability and education. This increase showed some fluctuations but generally trended upwards, with significant peaks in 2006, 2008, 2012, and 2019. The year 2019 marked the highest peak in the average citations per year, suggesting that articles published during those years had a significant impact and were frequently referenced in subsequent research. However, after this peak, the average citations per year started to decline again, especially after 2021, although they remained higher compared to the early years of the research period.

Overall, the graph shows that despite some fluctuations, the general trend indicates an increase in the average citations per year over time. This reflects the growing interest and influence of research on sustainability and education, highlighting the importance of this topic in scientific literature. The decline in citations after 2021 could be due to more recent articles not yet having had sufficient time to be recognized and referenced in other research.

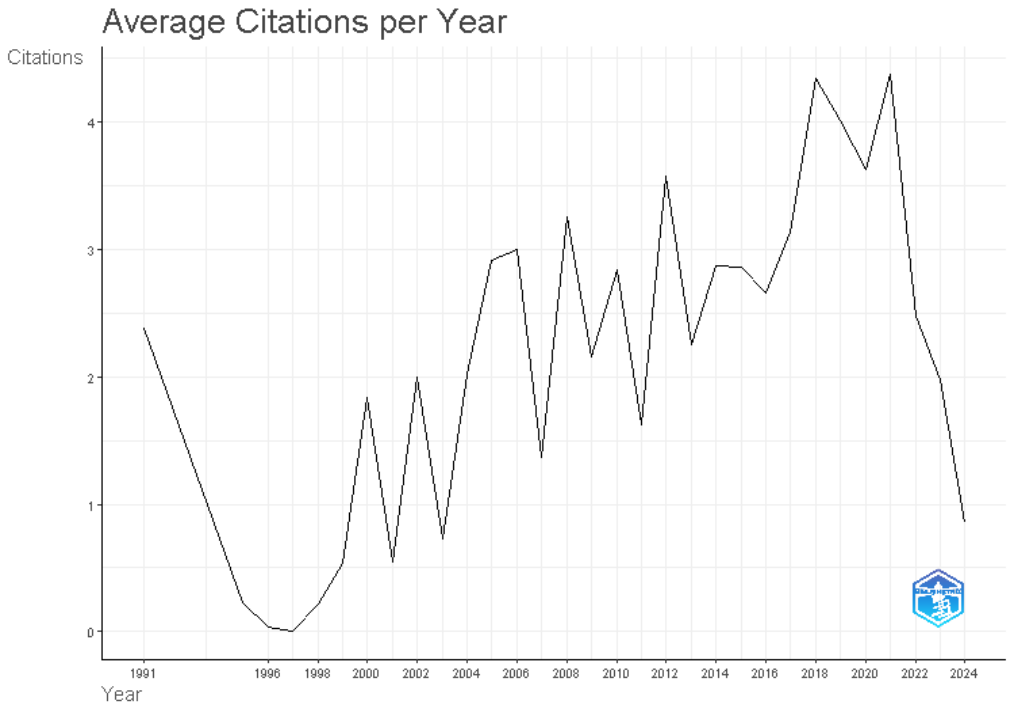

Figure 2. Average Citations per Year in the Sustainability Literature (1991–2024)

Thematic Development

The Sankey diagram illustrates the relationships between keywords (ID), authors (AU), and domains (DE)

related to research on sustainability and education. Key terms such as "sustainable development," "higher education," and "sustainability" are strongly linked to prominent authors like Leal Filho W, Brandli L, and Rieckmann M, who have significantly contributed to research in this field. The research domains are primarily connected to themes such as "higher education," "sustainability," and "sustainable development goals," highlighting the focus on the role of higher education institutions in promoting sustainable development goals. These authors dominate the field through their work that integrates issues of learning, curriculum, and the incorporation of sustainability in education, with universities acting as key players in the systemic shift towards global sustainability. The diagram reflects intense cross-topic collaboration, underscoring the substantial influence of educational institutions in achieving sustainable development.

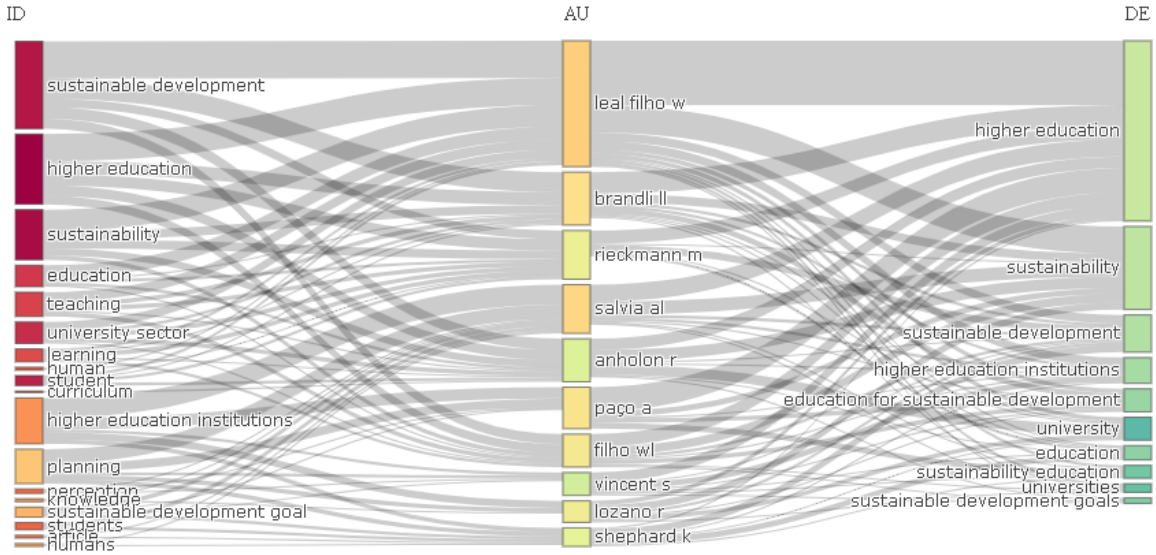

Figure 3. Thematic Development of Sustainability Research using Sankey Diagram

Researchers' Profiles and Source

Based on the data presented in the table and the accompanying Sankey diagram, it can be concluded that research in sustainability and education is primarily driven by a select group of prominent authors who have made substantial contributions in terms of article volume, h-index, and total citations. Leal Filho W emerges as the most prolific author, having published 51 articles, with a high h-index of 22 and a total of 2,756 citations, signifying a significant impact on the field. Lozano R also stands out with notable contributions, as reflected in his h-index of 14 and 2,072 citations, despite having published fewer articles (16), which underscores the high quality of his research.

Other authors such as Rieckmann M, Brandli LL, and Salvia AL have also played important roles, focusing on themes such as "higher education," "sustainability," and "sustainable development goals." The Sankey diagram illustrates the close relationship between these key authors and their research topics, as well as the areas of implementation, such as higher education institutions, which serve as centers of change toward sustainability. This data and diagram highlight the importance of interdisciplinary collaboration in integrating sustainability into education, covering aspects such as curriculum, learning, and global goals for sustainable development.

Table 2. List of Top Authors and their Contributions to Sustainability Research

No	Authors	N	Articles Fractionalized	h_index	Total Citation
1	Leal Filho W	51	9.07	22	2756
2	Salvia Al	22	2.39	15	852
3	Brandli Ll	17	2.21	13	1263
4	Paço A	17	2.42	10	834
5	Filho Wl	16	3.98	14	1017
6	Lozano R	16	5.27	14	2072
7	Rieckmann M	16	4.53	15	1742
8	Shephard K	16	5.43	9	791
9	Anholon R	15	2.08	11	697
10	Vincent S	15	5.78	8	286

The image depicts the distribution of publications by leading authors in the field of sustainability and education research over time. Leal Filho W emerges as the most prolific author, demonstrating a high and consistent rate of publication, especially from 2015 onward., with the size of the circles indicating the number of articles and citation intensity per year (TC per Year). Rieckmann M and Lozano R have produced highly impactful articles, as evidenced by the large circles representing high citation rates per year. The publication trend has collectively increased over the last decade, reflecting the growing global focus on integrating sustainability into education, especially within higher education institutions. This graph shows a concentrated contribution pattern, with many authors significantly increasing their productivity after 2010, aligning with the rising attention to the Sustainable Development Goals (SDGs).

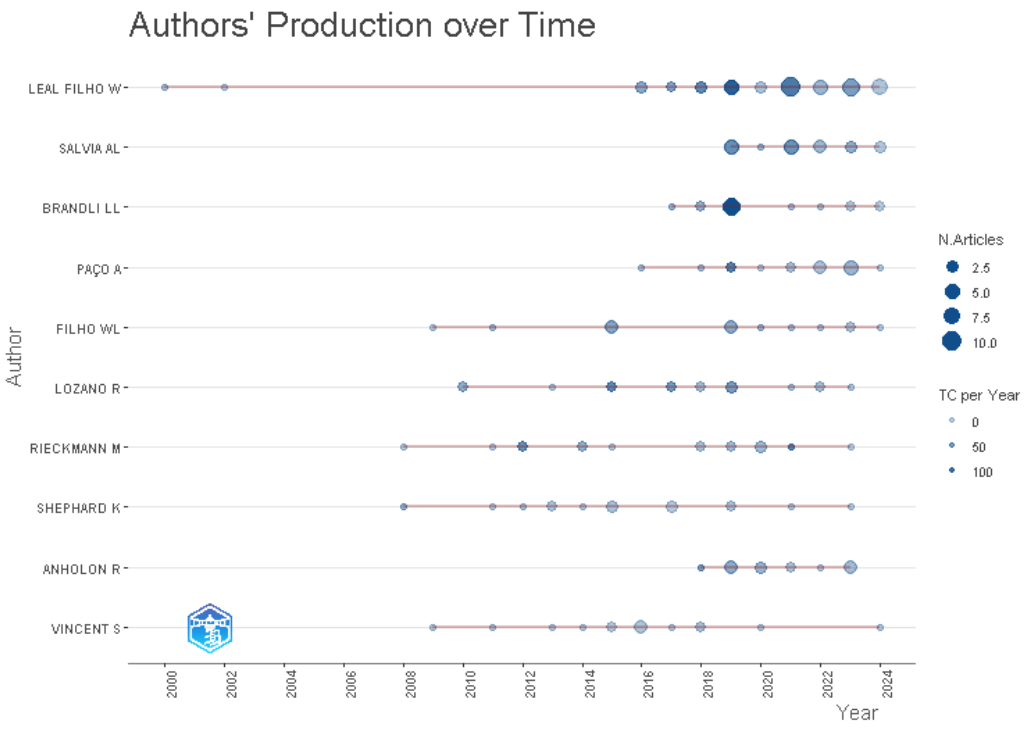

Figure 4. Top Author Production over Time

This graph illustrates the distribution of author productivity in bibliometric research on sustainability and education according to Lotka's Law. The graph displays a typical pattern of scientific productivity distribution, where most authors produce only a few documents, while a small number of authors are highly prolific. This is reflected in the sharp decline at the beginning of the curve, with the majority of contributions coming from a few authors, such as Leal Filho W, who produced 51 documents. This pattern indicates the field's reliance on intensive contributions from key authors, while the majority of authors contribute smaller amounts. It reveals a hierarchical collaboration structure, with most research contributions coming from leading experts in the field. The term The term "bibliometric" will be explicitly employed in all studies focused on quantifying the processes of written communication and is expected to gain widespread acceptance in the field of information science. Figure 5 illustrates author productivity based on Lotka's Law.

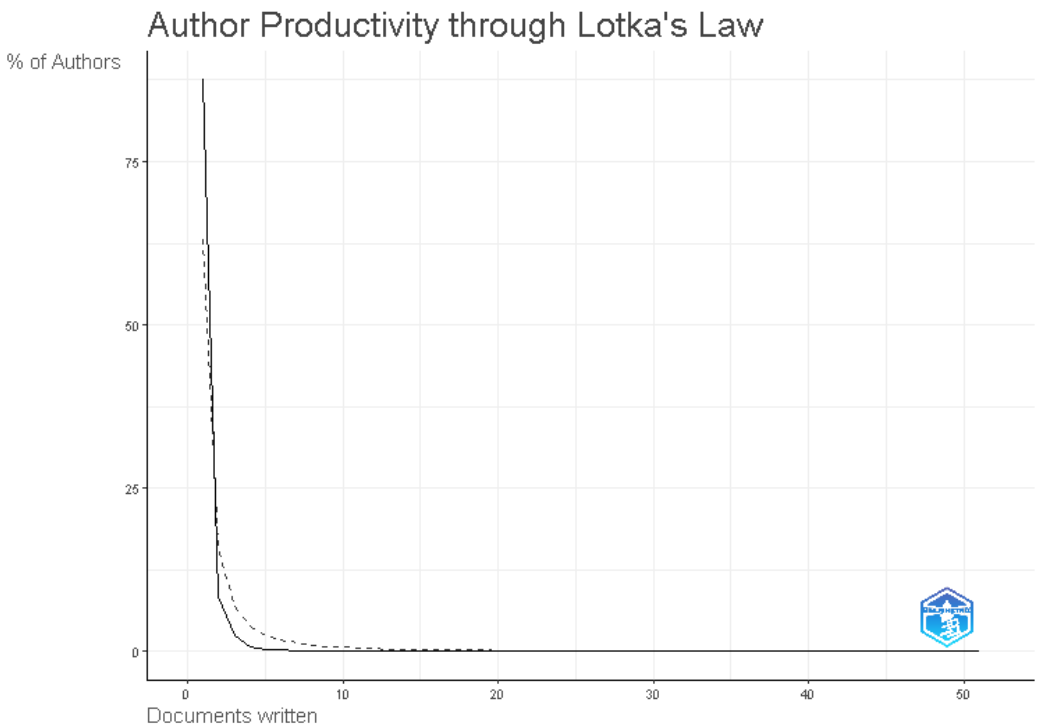

Figure 5. Author Productivity through Lotka's Law

Table 3 presents data on the key sources contributing to research on sustainability and education, along with their local impact. *Sustainability* (Switzerland) emerges as the With a CiteScore of 20.4, an h-index of 67, and a total of 14,075 citations, this journal plays a pivotal role in interdisciplinary sustainability research. Other notable sources, such as *Environmental Education Research* and *Environment, Development, and Sustainability*, also contribute significantly, though they publish fewer articles. These journals adopt diverse approaches to sustainability and education, ranging from policy perspectives to management and practical applications. Their influence continues to grow as global awareness of sustainability increases.

The concept of core ; Sources | N | CiteScore | h-index | g-index | m-index | TC | PY_start based on Bradford's Law, is used to identify the most productive journals in publishing articles related to sustainability and education. According to Bradford's Law, literature in a scientific field can be categorized into three zones: the

core zone, which contains journals with the highest number of articles, the second zone, which includes journals with moderate contributions, and the third zone, which contains journals with fewer contributions. Over time, from years 200 to 800, there has been significant development, especially in journals focused on sustainability and education.

Table 3. Top Sources and Their Local Impact

Sources	N	Cite Score	h_index	g_index	m_index	TC	PY_start
Sustainability (Switzerland)	784	6.8	56	83			
International Journal of Sustainability in Higher Education	544	6.6	58	99	2.32	15484	2000
Journal of Cleaner Production	197	20.4	67	110	2.91	14075	2002
Environmental Education Research	71	6.1	29	47	1.26	2359	2002
Environment, Development and Sustainability	37	10.2	13	22	0.81	524	2009
Sustainability (Switzerland)	37	6.8	4	7	0.67	70	2019
Education Sciences	36	N/A	9	15	1.13	277	2017
Cogent Education	30	2.3	1	2	0.17	8	2019
Sustainability (United States)	30	N/A	10	19	0.59	384	2008
Journal of Environmental Studies and Sciences	29	3.6	11	19	0.79	386	2011

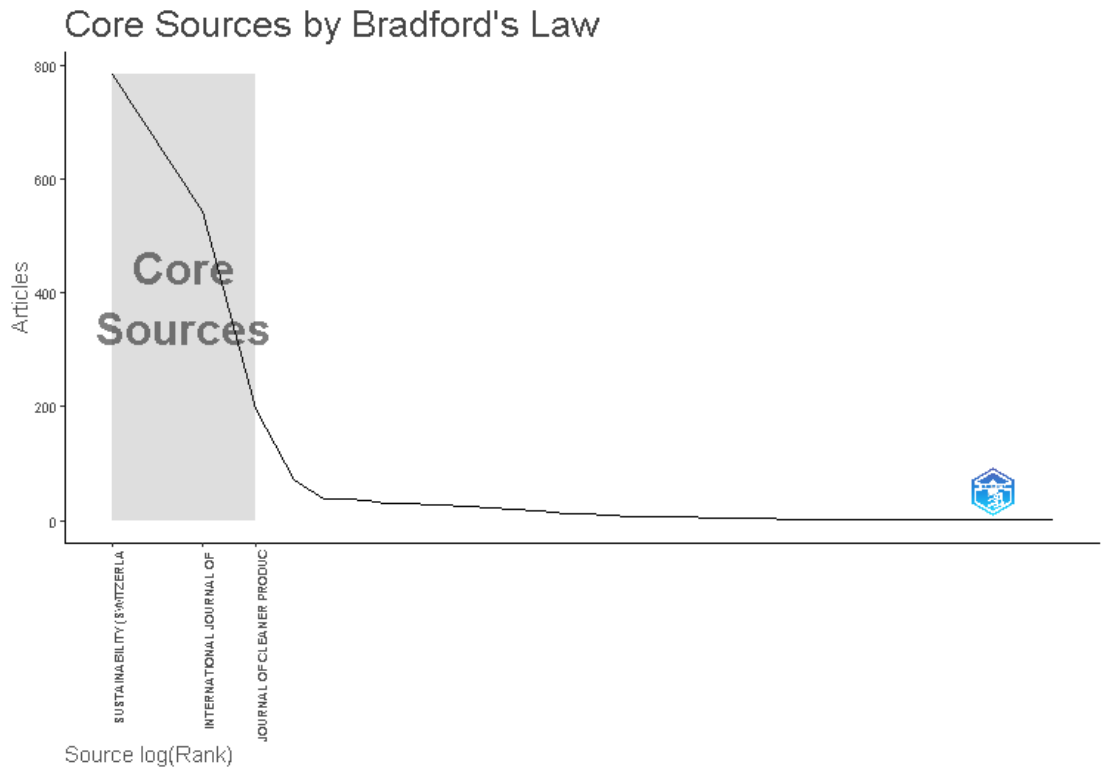

Figure 6. Core Sources through Bradford's Law

This analysis helps researchers identify the primary sources or journals that serve as the focal point of scholarly discussion, such as those that consistently publish high-quality articles and are frequently cited. Notable journals in this context include *International Journal of Sustainability* and *Journal of Cleaner Production*, which are central to the field due to their consistent contributions.

Data Source

The analysis of data sources in bibliometric research related to sustainability and education refers to the identification and selection of academic databases that serve as primary sources for collecting relevant literature. These data sources typically include databases such as Scopus, Web of Science, Google Scholar, and other databases with extensive collections of international scientific publications. In the context of this research, data sources are used to access articles covering various aspects of sustainability in education, including policy implementation, pedagogical practices, and environmental research.

This analysis is crucial to ensure that the data used in bibliometric research is comprehensive, credible, and includes publications from various disciplines and countries. This, in turn, enables researchers to accurately and systematically depict global trends and research dynamics in the field of sustainability and education.

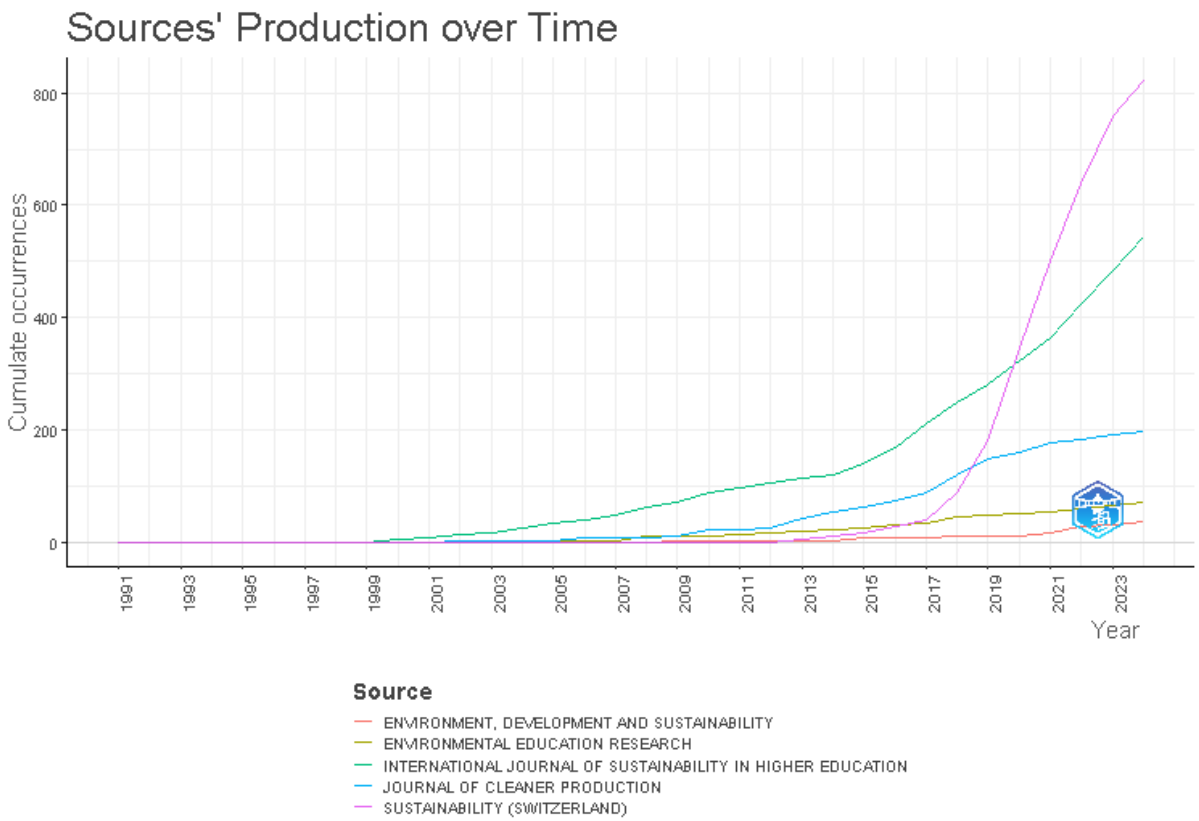

Figure 7. Top Sources Publication Growth

The journals *Environment, Development, and Sustainability*, *Environmental Education Research*, *International Journal of Sustainability in Higher Education*, *Journal of Cleaner Production*, and *Sustainability (Switzerland)*

have seen significant growth in publications related to sustainability since 1991. Notable increases in publication activity were observed starting from 2007, with the *International Journal of Sustainability in Higher Education* showing a notable rise in 2007, indicating a growing interest in sustainability within higher education. The *Journal of Cleaner Production* saw rapid growth beginning in 2009, reflecting its growing influence in industrial sustainability. *Sustainability (Switzerland)* experienced a sharp increase in publications in 2015, establishing itself as a key reference in sustainability research. Meanwhile, *Environmental Education Research* started to see significant growth in 2017, marking a rising emphasis on environmental education within the broader sustainability agenda. The growth of publications in these top sources highlights the expanding scope of research on sustainability across various domains, including education and industry, from 1991 to 2023.

Most influential literature

This bibliometric analysis reveals that the most cited papers on sustainability from 2013 to 2024 are predominantly contributions to the *Journal of Cleaner Production* (J CLEAN PROD) and the *International Journal of Sustainability in Higher Education* (INT J SUSTAIN HIGH EDUC). The paper by Lozano R, 2015, with a total of 572 citations and an average of 57.20 citations per year, leads as a primary reference in this field. Watermeyer R's 2021 paper has a significant impact with 551 citations and an exceptional annual citation rate of 137.75, reflecting its contemporary relevance. Classic papers such as Sipos Y, 2008, and Velazquez L, 2006, maintain strong relevance with a total of 522 and 508 citations, respectively, despite their earlier publication. Research by Leal Filho W, 2019, stands out with a high annual citation rate (63.50), highlighting the growing focus on sustainability over the last decade. Overall, the table emphasizes research trends and key contributions that shape the global understanding of sustainability and education.

Although the literature on Higher Education for Sustainable Development (HESD) includes contributions from scholars in 100 countries, there is a significant geographical imbalance. The majority of HESD studies are written by scholars from the United States, the United Kingdom, Canada, and Australia, who contribute 55% of the literature, as well as scholars from some Northern European countries who contribute 13%. In total, 84% of HESD documents come from developed countries, while only 16% come from developing countries. This imbalance could pose a challenge, as solutions developed in developed countries may not be easily applicable to developing nations (Hallinger & Chatpinyakoop, 2019).

Tabel 4. Most Highly Cited Sustainability Papers from 2013 to 2024

Rank	Total Citations	TC per Year	Author(s)/years	DOI	Source
1	572	57.20	(Lozano R, 2015)	10.1016/j.jclepro.2014.09.048	J Clean Prod
2	563	43.31	(Rieckmann M, 2012)	10.1016/j.futures.2011.09.005	Futures
3	551	137.75	(Watermeyer R, 2021)	10.1007/s10734-020-	High Educ

Rank	Total Citations	TC per Year	Author(s)/years	DOI	Source
				00561-y	
4	522	30.71	(Sipos Y, 2008)	10.1108/14676370810842193	Int J Sustain High Educ
5	508	26.74	(Velazquez L, 2006)	10.1016/j.jclepro.2005.12.008	J Clean Prod
6	421	24.76	(Shephard K, 2008)	10.1108/14676370810842201	Int J Sustain High Educ
7	403	50.38	(Lozano R, 2017)	10.3390/su9101889	Sustainability
8	395	26.33	(Brundiers K, 2010)	10.1108/14676371011077540	Int J Sustain High Educ
9	381	63.50	(Leal Filho W, 2019)	10.1016/j.jclepro.2019.05.309	J CLEAN PROD-A-B
10	333	30.27	(Wals Aej, 2014)	10.1016/j.jclepro.2013.06.007	J Clean Prod

Top Countries and Affiliations

The bibliometric table presents various journals that have contributed to research on the theme of "sustainability and education." Which includes Rank, Total Citations, Citations per Year, Author(s)/Year, and DOI.T he Journal of Cleaner Production has the greatest impact, with a Cite Score of 20.4, an h-index of 67, a g-index of 110, and a total citation Rank Total Citati ons TC per Year Author(s)/yearscount (TC) of 14,075 since its first publication in 2002, highlighting its global influence in sustainability research.

The International Journal of Sustainability in Higher Education is also a significant contributor, with a Cite Score of 6.6, an h-index of 58, and a total of 15,484 citations since 2000, underscoring its relevance in the field of higher education. Journals such as Sustainability (Switzerland) and Environmental Education Research consistently contribute, with Cite Scores of 6.8 and 6.1, respectively, and h-indices of 56 and 29. Newer contributors, such as Education Sciences and Cogent Education, show a smaller but still relevant impact in the field. These data reflect the importance of these journals in linking education to sustainability across various global contexts.

This bibliometric analysis reveals that the most cited papers on sustainability from 2013 to 2024 are dominated by contributions to the Journal of Cleaner Production (J CLEAN PROD) and the International Journal of Sustainability in Higher Education (INT J SUSTAIN HIGH EDUC). The paper by Lozano R, 2015, with a total of 572 citations and an average of 57.20 citations per year, leads the list as a primary reference in the field. Watermeyer R’s 2021 paper has significant impact, with 551 citations and an exceptional annual citation rate of 137.75, reflecting its contemporary relevance.

Classic articles such as Sipos Y, 2008, and Velazquez L, 2006, maintain their relevance with total citations of 522 and 508, respectively, despite being published earlier. Research by Leal Filho W, 2019, stands out with a high annual citation rate (63.50), underscoring the growing focus on sustainability in the last decade. Overall, this table highlights research trends and key contributions that shape **the** global understanding of sustainability and education.

Table 5. Countries with the Highest Number of Publications and Citations

Region	Freq	Total Citations	Average Article Citations
USA	1971	7992	15.9
SPAIN	1322	7652	23.4
UK	1077	6918	22.9
CHINA	795	3158	12.7
AUSTRALIA	774	4919	22.4
BRAZIL	707	2286	17.9
MALAYSIA	632	1678	11.7
PORTUGAL	477	2020	21.7
GERMANY	411	4894	35.7
ITALY	329	1721	21.5
USA	1971	7992	15.9

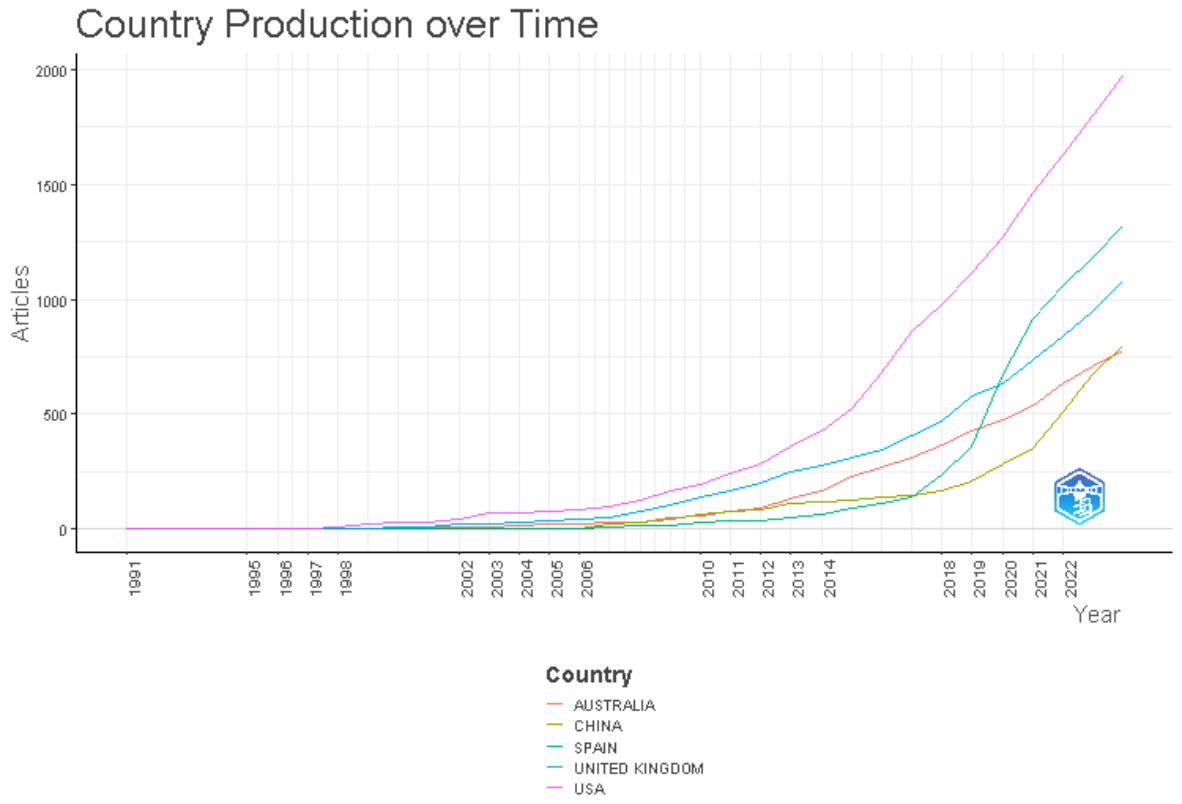

Figure 8. Document Growth of Sustainability by Country

Most Relevance

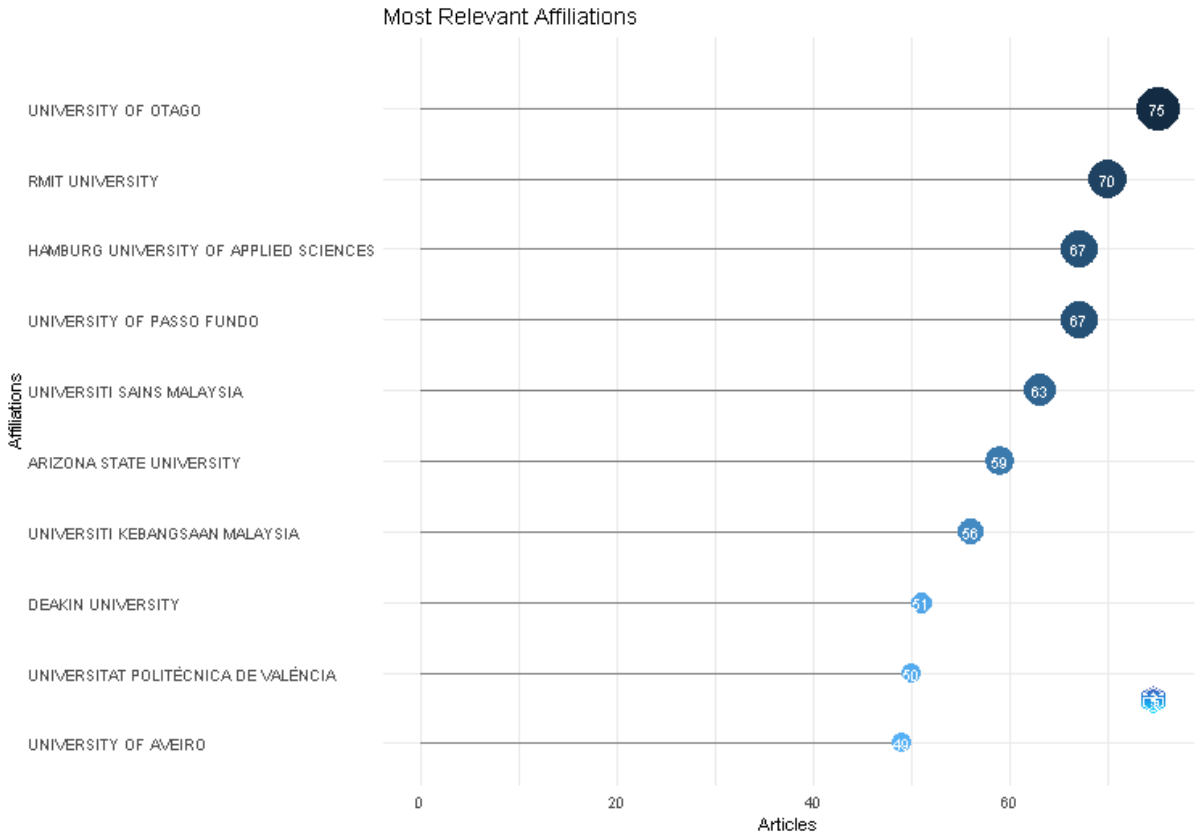

Figure 9. Top Affiliations

Keywords Trend

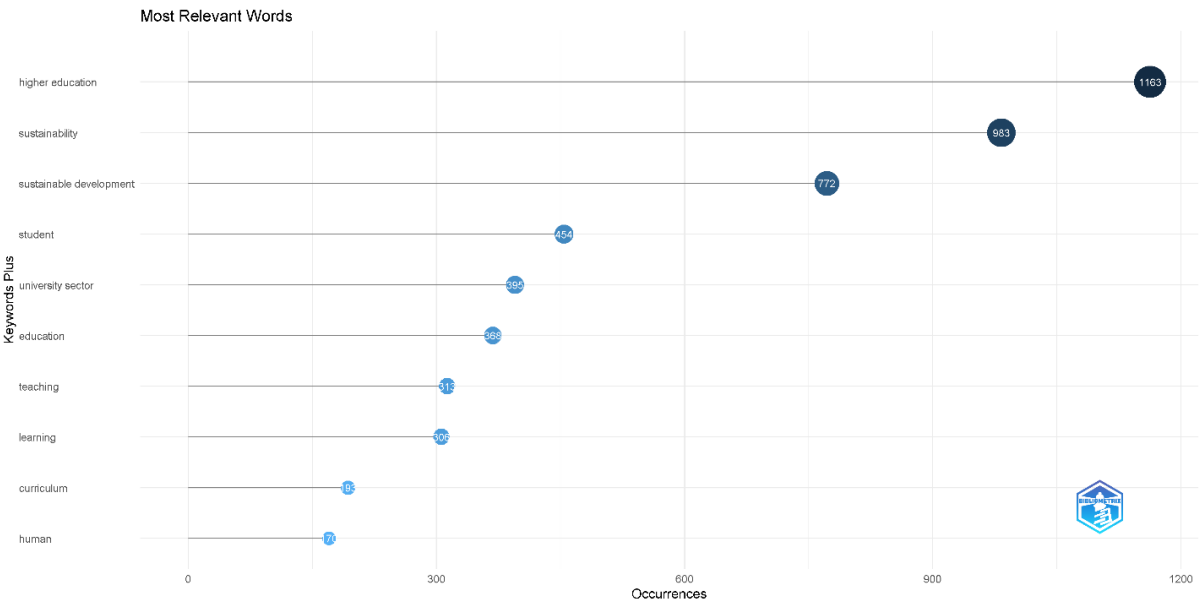

Figure 10. Most Frequent Words

Figure 10 highlights key terms such as curriculum, higher education, sustainability, education, teaching, and university teaching, reflecting the central focus of research on the integration of sustainability in education. Meanwhile, Figure 11 illustrates the trend of increasing frequency of these terms from 2009 to 2013, with a significant surge beginning in 2015, continuing through to its peak in 2017, 2019, and 2021, and is expected to persist into 2024. This increase reflects the growing attention to the integration of sustainability within curricula and teaching at the university level, in line with the rising global awareness of the importance of education in supporting sustainability goals.

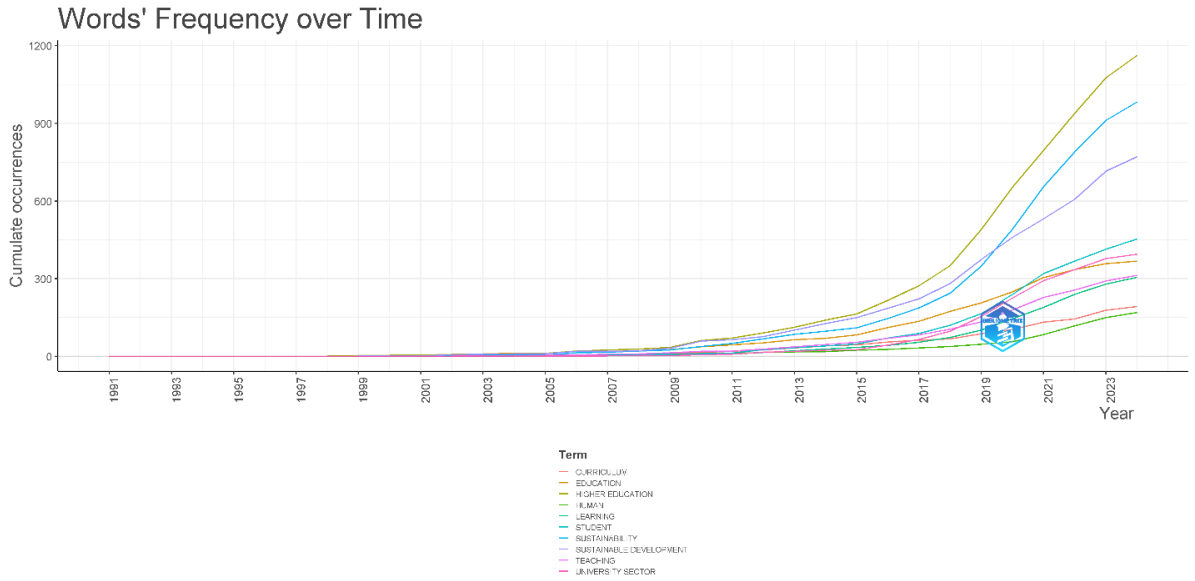

Figure 11. Words' Frequency over Time

Analysis of Knowledge Structures

The co-citation network analysis on the topic of sustainability and education reveals patterns of relationships between authors who are frequently cited together in academic literature. Authors with similar research focuses in this field tend to form clusters, reflecting their areas of expertise and influence within the academic community. For instance, authors who frequently study the implementation of sustainability education in school curricula are often cited together by other scholars investigating similar topics, thereby forming distinct clusters within the co-citation network. These co-citation relationships not only indicate thematic proximity but may also reflect collaboration among authors or the influence of a particular author on the development of research in sustainability and education. By analyzing these patterns, we can identify key authors and emerging research trends in this field.

Conceptual Structure of Thematic Evolution

In the conceptual analysis of the thematic map shown in Figure 12, the structure illustrates the co-occurrence network of various themes within the context of education and sustainability, highlighting a degree of alignment. Themes with a development status as "emerging or declining themes" include sustainable

development, higher education institutions, and other related topics. In this network, relevant themes such as education, Covid-19, leadership, sustainability in higher education, and students are identified as "emerging or declining themes" based on their degree of relevance. Meanwhile, the core themes in the thematic map, including education and sustainability, consistently appear in the conceptual structure analysis. This indicates that while some themes are evolving or fading, education and sustainability remain central focal points in research related to higher education and sustainability.

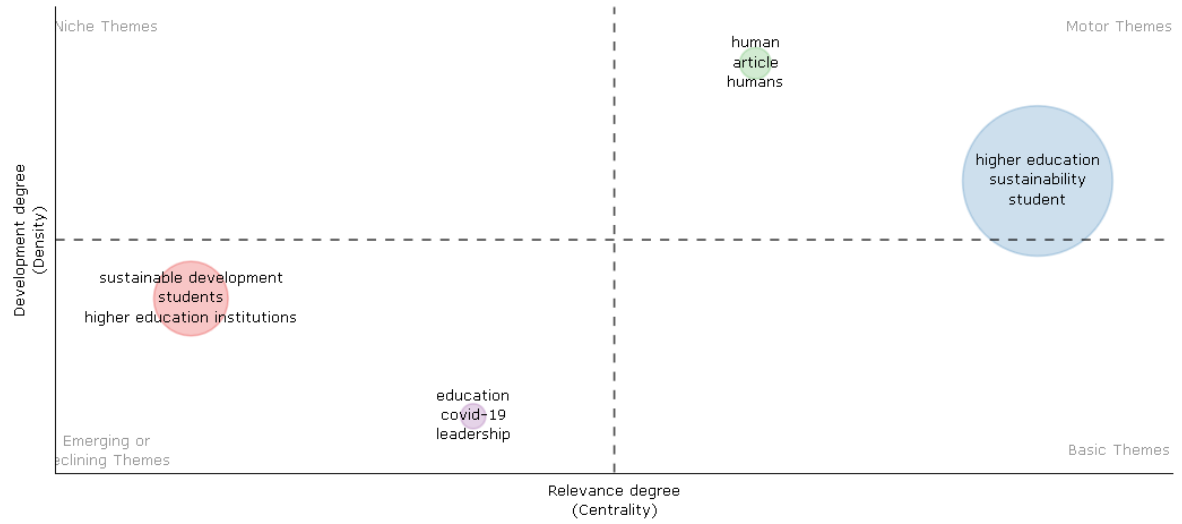

Figure 12. Thematic Map

The article on sustainability and education illustrates the thematic evolution from 1991 to 2024. During the period from 1991 to 2018, the main topics focused on sustainability, human issues, and higher education. From 2019 to 2022, the focus shifted towards higher education, human aspects, and higher education institutions. In the period from 2023 to 2024, the primary themes include higher education, sustainable development, and learning. This shift reflects a change in focus from the foundational concepts of sustainability and human education towards the integration of higher education with sustainable development and the enhancement of the learning process.

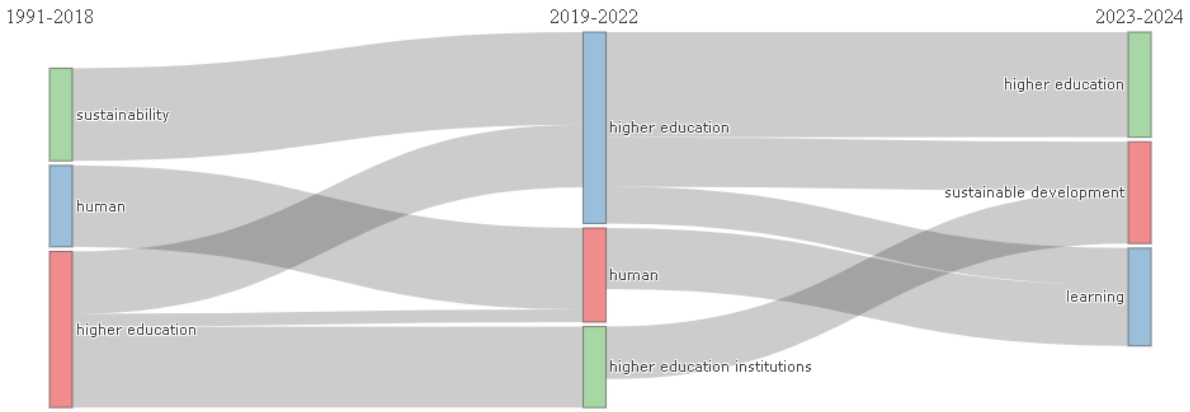

Figure 13. Factorial Analysis conducted using Multiple Correspondence Analysis (MCA)

Figure 15 in this journal article presents the results of a factorial analysis using Multiple Correspondence Analysis (MCA), which identifies the relationships between various factors influencing engineering education within the context of sustainability and higher education. The MCA reveals the connections between themes such as engineering education, curricula, higher education, and sustainable development, which interact within the educational planning process. Furthermore, factors such as decision-making, students, teaching, and innovation are also reflected in this analysis, illustrating how educational policies and teaching strategies can impact environmental awareness, climate change, and environmental protection. Themes related to perceptions at universities, human experimentation, as well as gender roles (female, male) and students are also examined, providing insights into how social and demographic elements contribute to sustainability education. Overall, this analysis highlights the complex relationships between various factors shaping sustainable engineering education and the impact of these factors on the development of education and environmental policies at the university level, with a case study from China as one example.

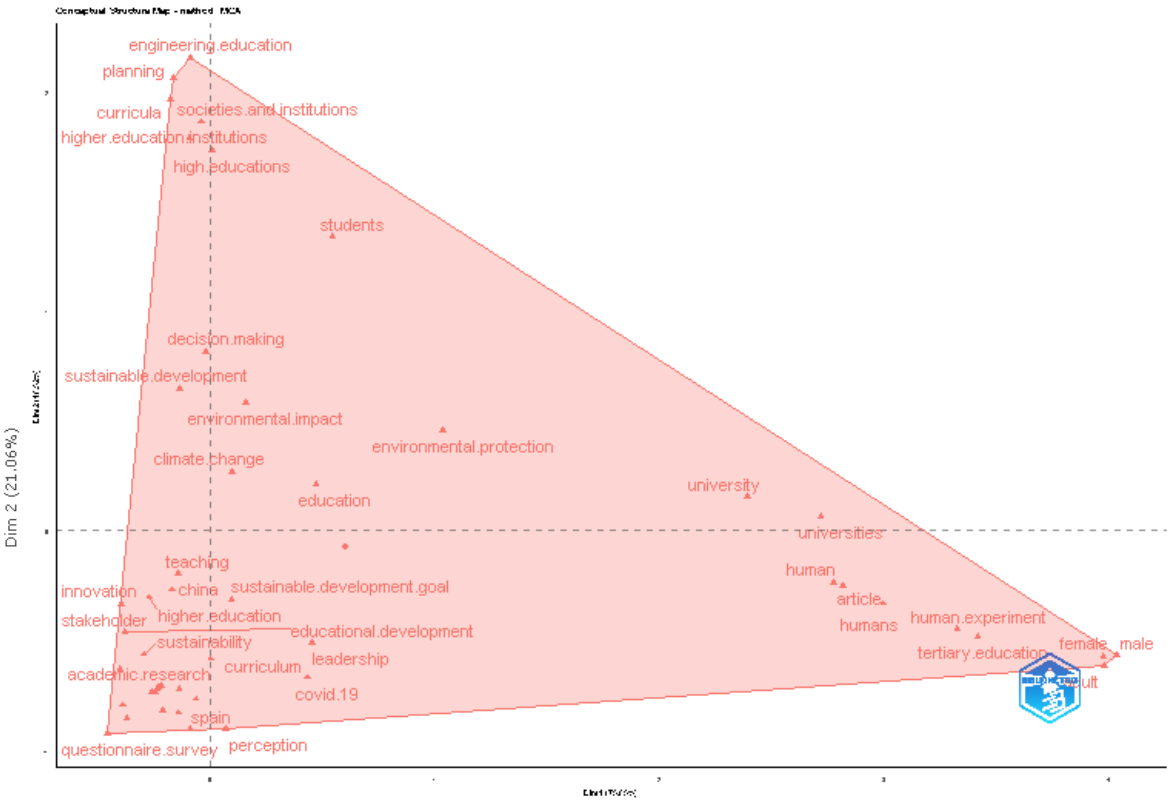

Figure 1 Factorial Analysis using MCA

The thematic dendrogram illustrates the relationships between various research themes related to sustainability and education by grouping them based on thematic proximity. The dendrogram includes a distance scale on the vertical axis ranging from 0.0 to 3.5, indicating the degree of similarity between the themes analyzed. A lower value on this scale suggests a closer relationship between themes. The thematic clusters formed include several key categories, such as those focused on human and social aspects (e.g., human, society, male, female), higher education institutions (e.g., universities, tertiary education, institutional framework), and methodological approaches (e.g., questionnaire survey, research work, interdisciplinary approach). Additionally, there are

clusters related to environmental education (e.g., environmental education, learning, knowledge), social impacts and the COVID-19 pandemic (e.g., perceptions, leadership), and international comparative themes (e.g., United States, Spain). This dendrogram reveals a strong connection between themes like human and society, highlighting the social dimensions of sustainability education, and underscores the importance of higher education in shaping sustainability policies at the institutional level. The interdisciplinary approach and the impact of the COVID-19 pandemic also emerge as crucial aspects in this thematic relationship pattern, reflecting the complexity and dynamics of sustainability research in education.

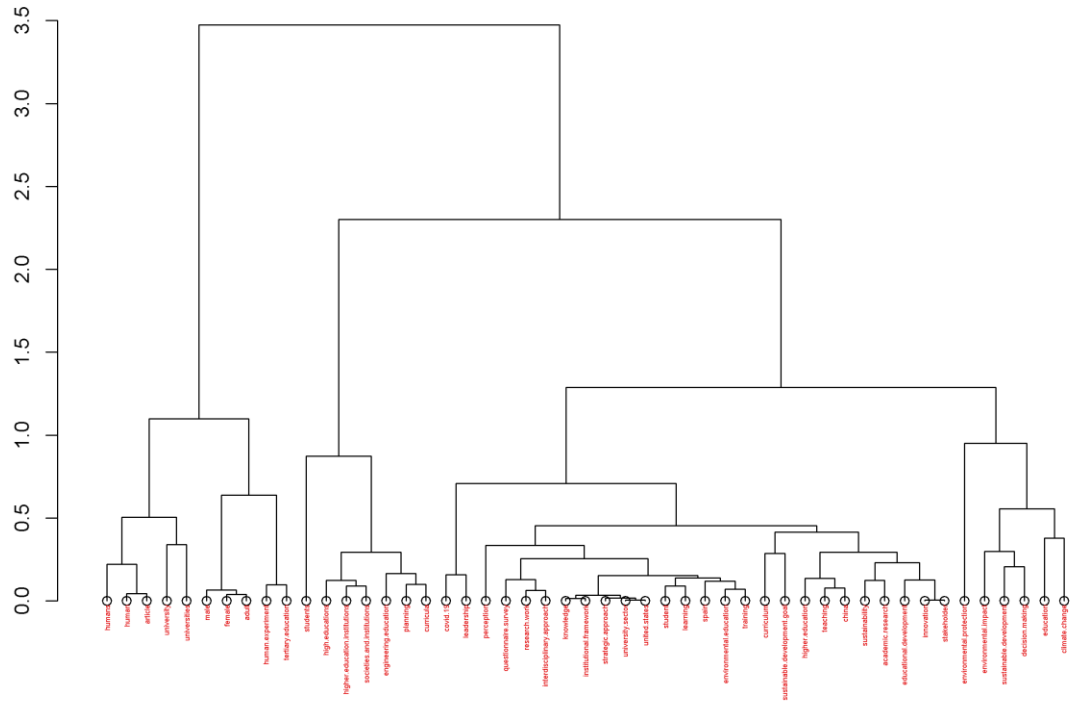

Figure 15. Thematic Dendrogram

Intellectual Structure

The Intellectual Structure diagram in bibliometric research on sustainability and education illustrates the conceptual map or the relationships between academic fields that underpin the topic, including key theories, methodological approaches, and central themes. This diagram serves as a foundation for understanding how the Collaboration Network (social structure) is formed, as interactions between authors are influenced by dominant ideas or theoretical frameworks. These relationships are also reflected in the Country Collaboration Map, which reveals patterns of international collaboration, reflecting the social and intellectual dynamics on a global scale. Thus, these various types of diagrams complement each other in analyzing the intellectual, social, and geographical interconnections within the fields of sustainability and education.

The co-citation network analysis on the topic of sustainability and education reveals patterns of relationships between authors who are frequently cited together in academic literature, reflecting the interconnectedness of

their ideas and areas of expertise. In this context, co-citation can be used to identify groups of authors with similar research focuses and map their influence on the development of research in the fields of sustainability and education.

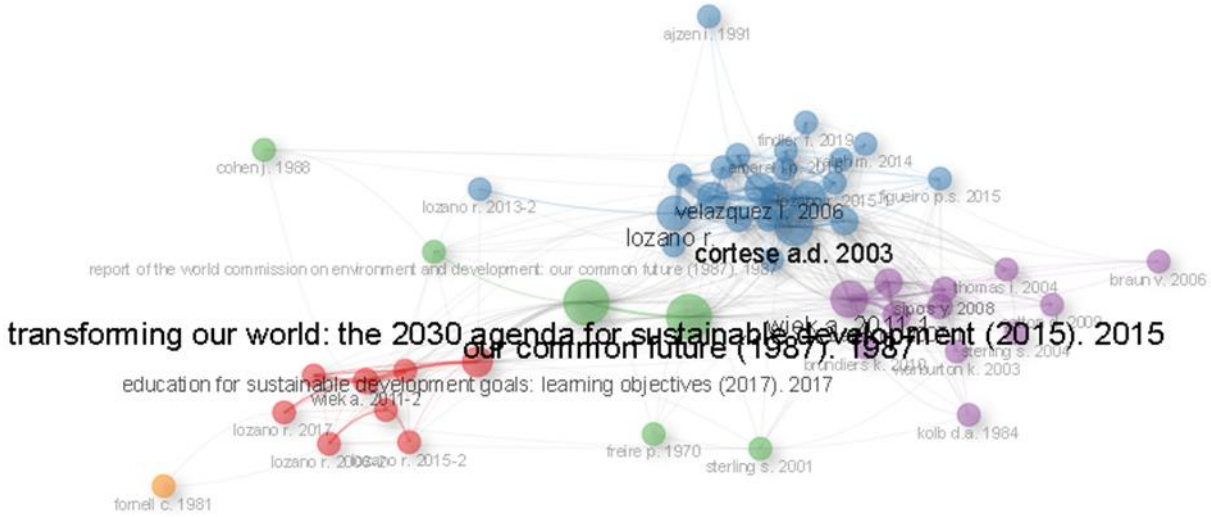

Figure 16. Co-citation Network

The co-citation network analysis on the topic of sustainability and education reveals patterns of relationships between authors who are frequently cited together in academic literature, reflecting the interconnectedness of their ideas and areas of expertise. In this context, co-citation can be used to identify groups of authors with similar research focuses and map their influence on the development of research in the fields of sustainability and education. The co-citation network analysis reveals the interconnections among authors who are frequently cited together, illustrating the relationship between their ideas and areas of expertise. Prominent scholars like Paulo Freire, known for his work on critical pedagogy, exert considerable influence on the discourse surrounding sustainability in education, as his works are often referenced by researchers exploring related topics. Alongside Freire, other authors such as Ozano, Fozano, Findler, and Cohen also appear prominently in the co-citation network, reflecting the increasing emphasis on the integration of sustainability in higher education and curriculum development. These clusters of authors with shared research interests contribute to the strengthening of the academic foundation in this area, with co-citation links also pointing to potential collaborations. Thus, this analysis not only maps thematic connections but also identifies emerging research trends and highlights key authors driving the development of sustainability education.

Social Structure

In the figure of the bibliometric data analysis related to the country collaboration map in this journal, insights are provided regarding the patterns of international collaboration in scientific research. This collaboration map identifies the countries most active in establishing academic partnerships and contributing to global research. The United States remains the dominant player, followed by Brazil, China, and Australia, while Indonesia's participation remains limited. In this analysis, key indicators such as the number of co-authored publications, the

strength of collaborative ties, and the geographical distribution of research partners are the primary focus. The data is typically processed using bibliometric software such as VOSviewer or Biblioshiny, which enables the visualization of international collaboration networks in an informative graphical format. The results of this analysis can help identify global trends, potential strategic partnerships, and gaps in scientific collaboration at the international level.

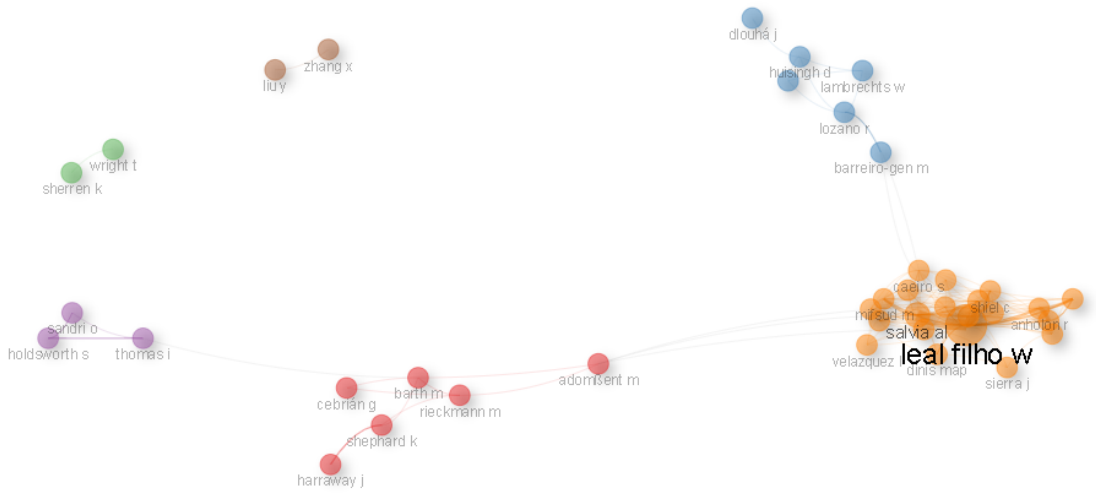

Figure 17. Collaboration Network

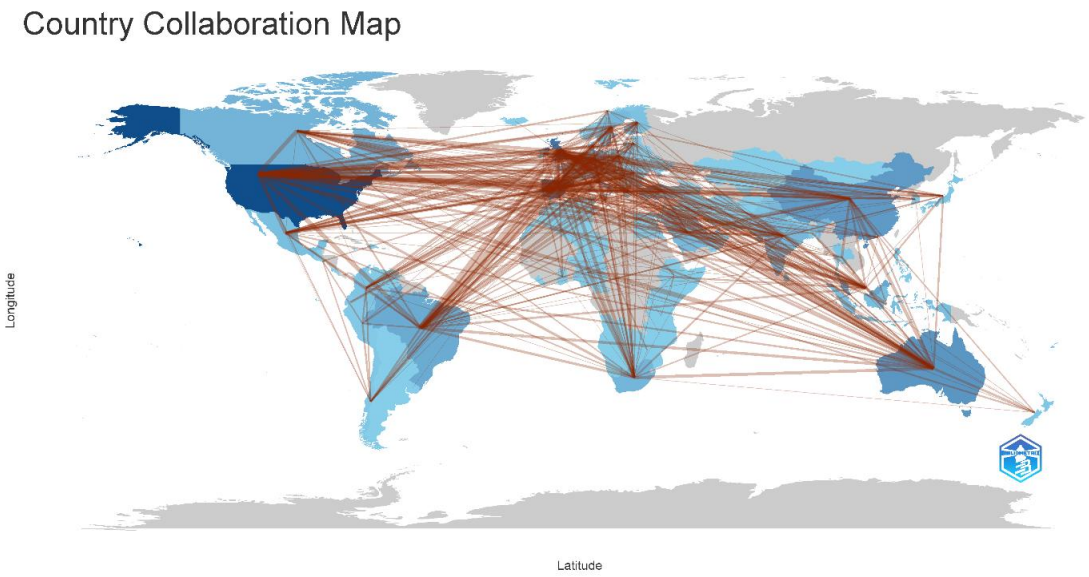

Figure 18. Country Collaboration Map

Conclusions and Implications

Summary of the findings are given below:

Number of documents: 4489

Annual growth rate (%): 20.98

Number of authors: 12218
Top author: LEAL FILHO W (n = 51)
Number of sources: 1318
The most productive source: SUSTAINABILITY (SWITZERLAND) (n = 784)
Top-cited article (DOI): 10.1016/j.jclepro.2014.09.048
The country with the most publications: USA (n = 1971)
University with the highest number of documents: University of Otago (n = 75)
The most favorite keywords: Higher education, sustainability, sustainable development, student, university sector

This information summarizes the key findings of the bibliometric analysis on research related to sustainability and education. With a total of 4,489 documents and an impressive annual growth rate of 20.98%, this field demonstrates rapid development. Contributions from 12,218 authors highlight extensive collaboration, with Leal Filho W emerging as the most prolific author with 51 documents. Among 1,318 sources, Sustainability (Switzerland) leads as the most productive journal, publishing 784 documents. The article with stands out as the most highly cited, reflecting its significant impact on sustainability literature.

The United States dominates with the highest number of publications (1,971 documents), while the University of Otago ranks as the top institutional contributor with 75 documents. Popular keywords, such as higher education, sustainability, and sustainable development, underscore a strong focus on higher education's role in supporting global sustainability efforts.

These findings illustrate the rapid and diverse evolution of research in this domain, driven by significant contributions from individuals, institutions, and countries. After assessing scientific output, researchers concentrated on co-citation analysis and employed algorithms to generate science maps and clusters. Co-citation analysis tracks pairs of articles cited together, where clusters form around recurring themes based on the frequency of co-citation. This analysis considered journals cited at least 20 times, ultimately identifying the top 10 most-cited articles.

Based on the analysis of articles related to "Sustainability and Education," several key points can be implicitly described, including: the Integration of Sustainability Principles, where this bibliometric emphasizes the importance of integrating sustainability principles and green chemistry into educational curricula to raise environmental awareness among students; Project-Based Learning Methods, which demonstrate that project-based learning is effective in developing students' critical thinking skills regarding sustainability issues, indicating that active learning can enhance students' understanding of environmental challenges; the Role of Policy, which highlights the crucial role of policymakers in creating a sustainable education framework aligned with the Sustainable Development Goals (SDGs). Policies that support sustainability education can strengthen efforts to achieve global goals; and the Positive Impact of Sustainability Education, which has a positive impact by reducing environmental footprints and preparing future generations to face increasingly complex environmental challenges.

A widely accepted conclusion is: Education that incorporates the principles of sustainability and green chemistry plays a crucial role in fostering environmental awareness and cultivating students' critical thinking abilities. By utilizing project-based learning methods and ensuring appropriate policy backing, we can cultivate a generation that is more environmentally conscious and equipped to tackle future sustainability challenges. By highlighting the significance of sustainability education, society is expected to develop a deeper understanding and provide stronger support for initiatives designed to improve the environment.

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Author Information

Tri Kurnia Fatmawati

https://orcid.org/0009-0009-7391-4026

Universitas Negeri Jakarta

Jl. Rawamangun Muka, RT.11/RW.14

Rawamangun, Pulo Gadung, Kota Jakarta Timur

Daerah Khusus Ibukota Jakarta 13220

Indonesia

Contact e-mail: *humas@unj.ac.id*

Irwanto Irwanto

https://orcid.org/0000-0001-5842-5931

Universitas Negeri Jakarta

Jl. Rawamangun Muka, RT.11/RW.14

Rawamangun, Pulo Gadung, Kota Jakarta Timur

Daerah Khusus Ibukota Jakarta 13220

Indonesia