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Research Article

A Comprehensive Bibliometric Analysis and Visualization of Publications on Environmental Innovation

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ABSTRACT

Environmental innovation has garnered increasing interest among scholars across diverse disciplines. This study presents a comprehensive analysis of environmental innovation literature from 1985 to 2022, reflecting the growing interest among academics from various disciplines. Utilizing VOSviewer and CiteSpace, 1552 relevant documents from the Web of Science Core Collection, underwent bibliometric analysis to discern trends and patterns. The study reveals a notable increase in academic interest in environmental innovation over time, evident from rising publications and citations. The environmental sciences ecology field emerges as the most cited domain. Research spans economics, education, sociology, and psychology, indicating a multidisciplinary approach. Notably, scholars from China, Europe, and the United States, including highly published Liao ZJ and Mazzanti M, have significant influence. Asian scholars, particularly from China, display substantial contributions. Co-occurrence analysis identifies key research hubs focusing on environmental innovation, eco-innovation, determinants, and performance. Recent breakthroughs center on environmental innovation, competitiveness, and determinants. Sustainability transition and environmental innovation remain significant areas of investigation, suggesting ongoing interest and potential for future advancements in the field. The University of Utrecht stands out for its prolific publications, while the University of Ferrara leads in citations per publication in environmental innovation research. This study provides valuable insights into the evolving landscape of environmental innovation research, offering opportunities for further advancement. It serves as a foundation for scholars and policymakers to address pressing environmental challenges and drive sustainable solutions through innovation.

Keywords: Environmental Innovation, Bibliometric Analysis, Citation Analysis, Keyword Analysis, VOSviewer, Citespace.

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INTRODUCTION

Management and economic literature have long regarded innovation as a topic of paramount significance. At the national level, innovation is seen as a significant factor in growth, development, and competitiveness. Because of its emphasis on transformation and the development or commercialization of new products, services, and processes, innovation necessitates unique, adaptable organizational structures at the business level. As a result of these factors, there is a wealth of literature about all kinds of innovations, including environmental innovation. Eco-innovation, as it is sometimes called, has gained widespread recognition as a key element of the innovation agenda.

Eco-innovation, or environmental innovation, is a relatively new concept in the literature on innovation. Its goal is to lessen the negative effects that technologies and manufacturing methods have on the environment. It has since sparked the curiosity of academics, who have sought to define eco-innovation and discover its drivers and constraints at multiple levels of research (from consumer and firm levels to industry and national levels).[1]

According to Kammerer,[2] environmental innovation encompasses all modifications and discoveries implemented by organizations to minimize their negative effects on the environment. In today's society, environmental innovation is increasingly recognized as a key factor in the success of new and innovative management strategies across organizations.[3] Kemp and Pearson[4] define an environmental innovation as "a product, production process, service, or management or business strategy that is unique to the organization that creates or implements it and that, for life cycle, reduces environmental risk, pollution, and other negative effects of resource use (including energy use)

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compared to similar alternatives." The phrase "throughout its life cycle" is essential here.

The concept of environmental innovation, described as innovation with a specific focus on the environment, is attracting the attention of scholars from a broad scope of academic fields. Studies in energy, ecology, economics, politics, geography, transportation, management, science and technology, and political science all play a role.[1] For almost two decades, there has been steady development in the eco-innovation area. With the growth in globalization over the last decade, the importance of environmentally innovative practices has increased. Although there is widespread interest in environmental innovation, no comprehensive bibliometric analysis has focused on this topic thus far. Although there is widespread interest in environmental innovation, few comprehensive bibliometric analyses have focused on this topic and more in the general innovation field thus far.[5-7] In a recent study, Šūmakaris and Korsakienė[6] investigated and mapped eco-innovation strategies at the firm level. Their analysis encompassed 929 scientific publications from the ISI Web of Science (WoS) database published between 1990 and 2020. Notably, the findings indicated a growing interest in the field, particularly in the last five years. This reveals that research on eco-innovation strategies is relatively new and gaining traction.

Similarly, Šūmakaris, Ščeulovs[7] delved into eco-innovation and internationalization through a bibliometric analysis of 1677 publications from the Web of Science database between 1991 and 2020, employing VOSviewer software. Their investigation confirmed an exponential growth in scientific publications on the selected topics every year. They also found that developed countries, such as the USA and the United Kingdom, significantly influenced research on these topics.

Albort-Morant, Henseler[8] conducted a bibliometric analysis of Green Innovation (GI) literature between 1971 and 2015, focusing on publications available in the Web of Science (WoS). Their research revealed substantial growth in the field of GI since the 1970s, particularly in recent years, indicating a significant impact on the literature. Moreover, the diverse nature of scholars approaching this topic, including disciplines like management, economics, engineering, and biology, reflects the strong interest that GI research has garnered.

In another study, Barbieri, Ghisetti[9] conducted a literature survey on Environmental Innovation (EI) using main path analysis. The study identified four main themes within the EI literature: determinants of EI; economic effects of EI; environmental effects of EI; and policy inducement in EI.

The moment is right to present such a comprehensive assessment, examining the trend, research directions, academic advancement, policy developments, and environmental management and performance acquired from this field of study.

A comprehensive framework might be gleaned from an in-depth analysis of this literature review employing rigorous bibliometric methods. The study results would also recommend moving forward in several emerging areas.

An in-depth bibliometric study of publications can disclose an institution's academic strength and the possibility of citation or co-citation models, promoting the investigation and clarification of a discipline's major work contents and progression.[10] When constructing a scientific framework for research topics, the bibliometric method may prove superior to the more conventional structured approach, especially when dealing with large publications.[11] Furthermore, they stress the significance of a field's knowledge institutions and recent developments for the direction of future study.[12-14] This review uses the VOSviewer software,[15] which was chosen for its robust graphic interface and ability to build maps to describe the links between each analysis unit. Burst detection, dual-map overlay, and timeline view are all visualized with the help of a different software program called CiteSpace.[16]

The purpose of conducting this bibliometric analysis was to comprehend better the fundamental features and dynamic changes of environmental innovation literature to understand better research hotspots, frontiers, and trends in the area. In particular, three main contributions may be attributed to this study. First, we strive to comprehensively understand the background analysis of documents related to environmental innovation, such as document categories, research areas, and highly cited publications. Second, we analyze the published works from three aspects: country or region, institution, and author. The authors, sources, countries, and institutions are then subjected to a burst analysis to determine the field's current state. Finally, we evaluate keywords from three angles (co-occurrence analysis, burst detection analysis, and timeline view analysis) to understand the underlying patterns and trends in environmental innovation.

The remaining sections of this study are structured as follows: present the bibliometric techniques and data sources employed in the research. Then, the analysis outcomes and discussions are shown, including the background analysis, citation analysis, burst detection analysis, and keyword analysis conducted with VOSviewer and CiteSpace. As the research comes to a close, give a summary, any important limitations, and ideas for further research.

METHODOLOGY

There are three motivations for using bibliometric analysis in this study. Compared to other text analysis methods, such as content analysis, bibliometric analysis is more efficient and accurate for dealing with hundreds of publications. Second, bibliometric analysis can provide an in-depth analysis of relationships between

publications, citations, co-citations, and keywords, providing thorough information in our research field. Last but not least, it has excellent visualization capabilities for bibliometric analysis, which allows readers to quickly and easily pinpoint areas of interest for further study.

Bibliometric methods

Knowledge analysis using bibliometrics can be performed on any study topic to unearth objective and unobservable trends.[17-21] The bibliometric method provides a quantitative approach to managing the exponentially expanding literature in every discipline. Gelphi, BibExcel, the VOSviewer, and CiteSpace are a few of the numerous developed bibliometric resources. It is important to consider how useful and easy a bibliometric instrument is to use before committing to it. VOSviewer and CiteSpace are two bibliometric analysis programs that are easier to use than the others since they do not necessitate programming knowledge from the user and feature specific parameter settings. Because all we have to do to get started is copy and paste some text containing our data, these programs have quickly gained popularity among beginners looking for simple analysis solutions. Bibliometric research should incorporate background analysis and collaborative network analysis, including techniques like bibliographic coupling, co-citation, and co-occurrence analysis. The VOSviewer displays bibliographic coupling, co-citation, and co-occurrence optical node networks using two scales to measure: the number of links and overall strength.[22] Donthu, Kumar[23] and Martínez-López, Merigó[24] report that the VOSviewer can manage vast volumes of data, has improved mapping capabilities, and supports all the functionalities investigated here.

CiteSpace is a useful bibliometric tool that can be used to create time-varying burst detection methods and time-zone views.[16] CiteSpace is very important for predicting the future of research and studying how research hotspots change.[25,26]

Data source

The data utilized in this research was extracted from the Web of Science (WoS) Core Collection on the Web of Science which primarily includes the Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (AHCI), Emerging Sources Citation Index (ESCI), Conference Proceedings Citation Index and Book Citation Index. WoS is the most popular and useful database for bibliometric studies of scientific publications because it has a strict process for evaluating information and gives the most important and reliable information.[5] Future research work can conduct a comparative analysis using two or more databases.[27]

We investigated the databases most frequently utilized by researchers on WoS to access and collect credible documents.[28] The Core Collection of the Web of Science is a compilation of the journal's most authoritative publications. For this reason, we limited our search to "Database = Web of Science Core Collection" and used the "TS = environmental innovation" retrieval formula in the "Advanced Search" field, specifying a time range from 1985 to 2022. Thus, the search terms are, (Search in: "Web of Science Core Collection"), (Editions: "All") AND (Document: (Topic: "environmental innovation") AND (Publication Date: 1985-2022). Out of these documents, 1544 are in English, Spanish (4), Chinese (2), French (1) and German (1) languages. The search keyword "environmental innovation" was exclusive used to obtain specifically research study relating to environmental innovation rather than general innovations. After retrieving 1552 documents, we used tab-delimited file formats to export the necessary information from the WoS. This information included the full record and references.

RESULTS

Background analysis

The fundamentals of the literature can be obtained from preliminary data analysis.[29] This section explains how publications, citations, and research directions in environmental innovation have evolved. Figures 1-4 depict the findings. There are 1552 documents in the dataset, which spans from 1985 to 2022.

We can observe the shift in these metrics throughout more than three decades of environmental innovation research in Figure 1. There is an increasing pattern of publication, with peaks in 2011 (20), 2017 (92), and 2022 (250). The total number of publications has skyrocketed since 2010. The increasing numbers indicate a widespread consensus among experts on the field's significance. This pattern also signifies that the number of publications will keep rising.

The distribution of citations is seen in Figure 2. The rising graph of citations reaches its maximum in 2022 (13276). The rise suggests

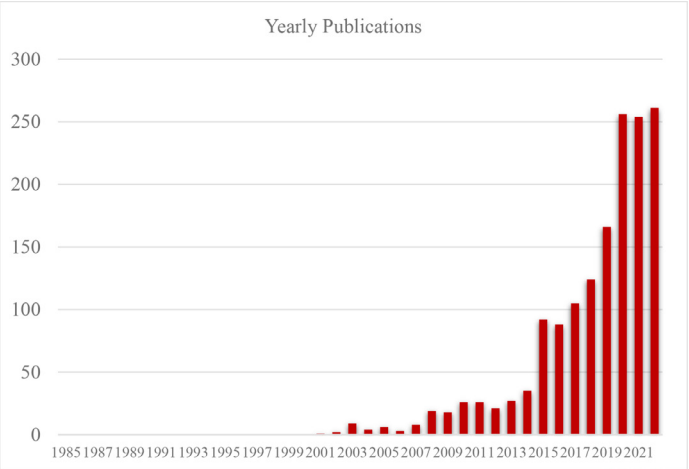

Figure 1: Yearly Publication trend of environmental innovation.

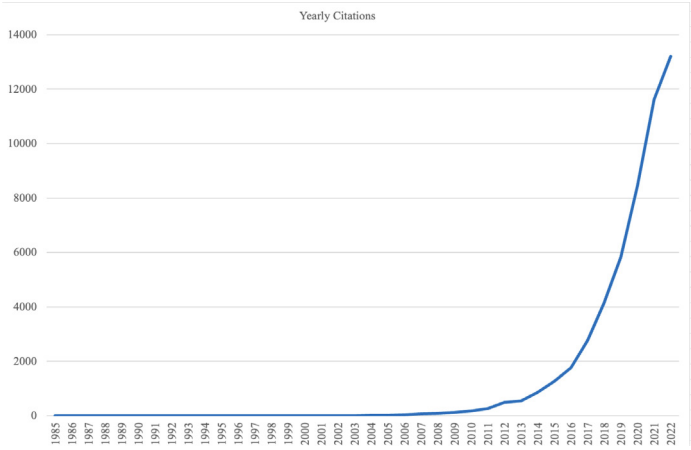

Figure 2: Yearly citations trend of environmental innovation.

Figure 3: Top 15 publications outputs based on research area.

Source: Web of Science.

that scholars have begun paying more attention to environmental innovation in recent years. Significant emphasis has been paid to boosting environmental innovation research's productivity and citation effect over the past few years.

The documents mentioned 60 distinct research categories; the top 15 are summarized in Figure 3. Environmental sciences ecology (1093, 70.43%) is far and away the most common topic of study concerning environmental innovation. For other areas of study, the percentages are pretty consistent, including business economics (451, 29.06%), science technology other topics (261, 16.82%), and engineering (213, 13.72%). Public documents show that while environmental sciences ecology has emerged as the primary focus of the environmental innovation domain, other areas are also receiving significant attention and investment.

In Figure 4, we can observe the distribution of different types of publications covering environmental innovation. Articles (1398, 90.08%) were the most common type of publication among the 1552 total works; these were followed by early access articles

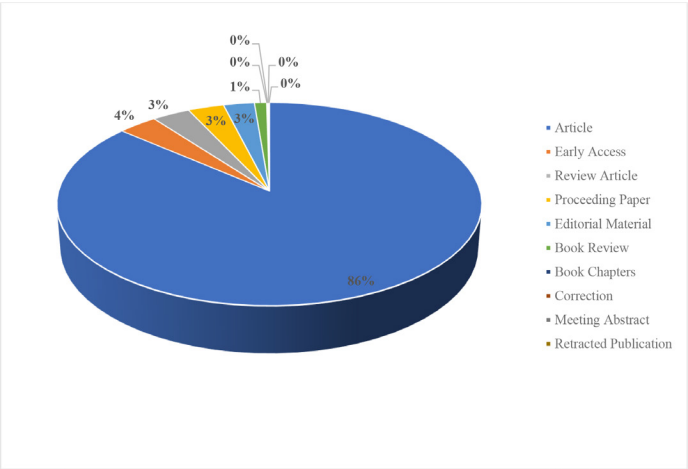

Figure 4: Types of publication document.

(55, 3.54%), review articles (53, 3.42%), proceedings papers (50, 3.22%), editorial materials (43, 2.77%), book reviews (17, 1.10%), and the rest (book chapters, corrections, meeting abstracts, retracted publications; 1, 0.06%). Because a given document may fit into multiple categories simultaneously, the total number of document types exceeds the document number.

There are 1552 documents on the subject, distributed among 335 journals. We can see the top 10 journals that have published the most articles on environmental innovation in Table 1. Notably, 1072 out of 1552 are articles (roughly 90%) published in only 20 journals. When sorted by several documents, the first-place winner is Environmental Innovation and Societal Transitions, with 546. Journal of Cleaner Production (122), which is a close second, and Sustainability (79) round out the top three. Business Strategy and the Environment is a leading journal on management, and it has published 74 documents. Therefore, this indicates an increase in the acceptance of environmental innovation among management professionals. Also, our findings support this hypothesis consistent with Bradford's Law (1934), which states that only a few periodicals tend to publish the vast majority of papers on any given topic. Finally, these findings from the published literature on environmental innovation imply that the subject is of interest to researchers from several disciplines.

Citation analysis

In the academic world, influence is typically measured by the frequency with which a publication is cited. People in the field will regard the publication or the author as influential if their work has received substantial citations.[30]

Influential Authors

According to WoS, there have been 3,558 unique authors involved in the publication of research in the area of environmental innovation. VOSviewer was analyzed to determine which authors have the most publications in the field of environmental

Table 1: Top 20 journals in terms of number of publications on environmental innovation.

Rank	Journals	Publications
1	Environmental Innovation and Societal Transitions	546
2	Journal of Cleaner Production	122
3	Sustainability	79
4	Business Strategy and The Environment	74
5	Technological Forecasting and Social Change	43
6	Research Policy	28
7	Ecological Economics	27
8	Environmental Science and Pollution Research	20
9	Corporate Social Responsibility and Environmental Management	18
10	Journal of Environmental Management	17
11	Industry and Innovation	14
12	International Journal of Environmental Research and Public Health	14
13	European Journal of Innovation Management	11
14	Energy Policy	10
15	Journal of Environmental Planning and Management	10
16	Sustainable Development	10
17	Environmental Engineering and Management Journal	8
18	Energy Economics	7
19	Environmental Resource Economics	7
20	Journal of Business Ethics	7

innovation. Listed in Table 2 are the 20 most prominent authors. As can be seen in the Table 2, Liao Zhongju has the most published works (29). After Massimiliano Mazzanti (19), the next highest-ranking authors have 17 and 12, respectively. Such findings suggest that the field is developing, as there are not yet many defining authors and scholars from different kinds of disciplines making contributions.

Highly cited authors

Table 3 displays the ten most often cited authors. Truffer, Bernhard, and Raven, Rob, who both feature on the list of authors with the most publications, are also among the authors with the most citations, as seen in Table 3. This finding suggests that both authors have widely read and influential publications.

Table 2: Top 20 influential authors.

Rank	Authors	Publications
1	Liao, Zhongju	29
2	Mazzanti, Massimiliano	19
3	Raven, Rob	17
4	Truffer, Bernhard	17
5	Hekkert, Marko P.	12
6	Kivimaa, Paula	12
7	Aldieri, Luigi	11
8	Kern, Florian	11
9	Saez-Martinez, Francisco J.	11
10	Sovacool, Benjamin K.	11
11	Triguero, Angela	11
12	Vinci, Concetto Paolo	11
13	Elliott, Kyle H.	9
14	Horbach, Jens	9
15	Alkemade, Floortje	8
16	Bergek, Anna	8
17	Boon, Wouter P. C.	8
18	Frenken, Koen	8
19	Ghisetti, Claudia	8
20	Gonzalez-Moreno, Angela	8

Table 3: Top 20 most cited authors.

Rank	Authors	Citations	Average Citation
1	Truffer, Bernhard	2428	142.82
2	Raven, Rob	2110	131.88
3	Markard, Jochen	2056	293.71
4	Horbach, Jens	1503	167
5	De Marchi, Valentina	1163	166.14
6	Mazzanti, Massimiliano	1045	58.06
7	Ghisetti, Claudia	970	121.25
8	Rennings, Klaus	962	192.4
9	Coenen, Lars	865	144.17
10	Frenken, Koen	752	94
11	Triguero, Angela	647	64.7
12	Liao, Zhongju	622	21.47
13	Cainelli, Giulio	539	107.8
14	Moreno-Mondejar, Lourdes	494	98.8
15	Saez-Martinez, Francisco J.	433	54.13
16	Kern, Florian	430	43
17	Hekkert, Marko	429	71.5
18	Del Rio, Pablo	414	59.14
19	Bergek, Anna	408	58.29
20	Gonzalez-Moreno, Angela	394	49.25

Table 4: Top 20 most cited publications of environmental innovation.

Rank	Publications	Journals	Year	Citations	Average
1	Horbach[31]	Research Policy	2008	843	56.2
2	Brunnermeier and Cohen[32]	Journal of Environmental Economics and Management	2003	769	38.45
3	Kohler, Geels[33]	Environmental Innovation and Societal Transitions	2019	693	173.25
4	De Marchi[34]	Research Policy	2012	643	58.45
5	Berrone, Fosfuri[35]	Strategic Management Journal	2013	589	58.9
6	Frenken and Schor[36]	Environmental Innovation and Societal Transitions	2017	527	87.83
7	Adams, Jeanrenaud[37]	International Journal of Management Reviews	2016	495	70.71
8	Gold, Seuring[38]	Corporate Social Responsibility and Environmental Management	2010	494	38
9	Schiederig, Tietze[39]	R & D Management	2012	418	38
10	Hansen and Steen[40]	Environmental Innovation and Societal Transitions	2015	400	50
11	Triguero, Moreno-Mondejar[41]	Ecological Economics	2013	393	39.3
12	Kesidou and Demirel[42]	Research Policy	2012	391	35.55
13	Zhang, Peng[43]	Energy Policy	2017	386	64.33
14	Eiadat, Kelly[44]	Journal of World Business	2008	337	22.47
15	Kammerer[2]	Ecological Economics	2009	328	29.82
16	Truffer and Coenen[45]	Regional Studies	2009	328	23.43
17	Rehfeld, Rennings[46]	Ecological Economics	2007	306	19.13
18	Simpson and Power[47]	Supply Chain Management	2005	301	16.72
19	Beise and Rennings[48]	Ecological Economics	2005	291	16.17
20	Bocker and Meelen[49]	Environmental Innovation and Societal Transition	2017	282	47

The frequency with which a publication is referenced in another is sometimes used as a benchmark for how influential that publication is. The fact that several of these documents are the outcome of international cooperation in environmental innovation shows a lot of communication and collaboration among academics.

Highly-cited publications

The frequency with which a document is cited is an indication of its significance and prominence. Table 4 gives a full look at the 20 most-cited publications about environmental innovation, including information about the author, the year, and the publication.

Having accumulated 1530 citations, Horbach[31] work stands out as the most cited, followed by those of Brunnermeier and Cohen,[32] Kohler, Geels[33] and others. There is a lot of communication and collaboration amongst academics, as evidenced by the fact that several of these documents are the results of international cooperation on the subject of environmental innovation.

Moreover, "Economics, Economic, Political," and "Psychology, Education, Social" form the foundation of the domain of frontier research. The documents categorized as "Economics, Economics, Political" and "Psychology, Education, and Health" connect to a broad scope of academic fields. The research on ecological innovations demonstrates a transdisciplinary nature. Each ellipse's size on the map is proportional to the total of authors and linked documents for that specific area.[50] There is a correlation between the number of writers and citations for works in the "Economics, Economic, Political" and "Psychology, Education, Social." The statistical results for the top 20 research directions shown in Figure 5 and the information represented by the journal dual-map overlay are consistent. Economics, education, society, and health have all been the subject of numerous recent publications on environmental innovation.

Authors affiliation

To analyze the data, VOSviewer was used specifically to extract the entire record and references for each author and to order and descend all author organizations. According to WoS, 1,543 institutions have published on the subject of environmental innovation. The 20 most prolific publishers of works on

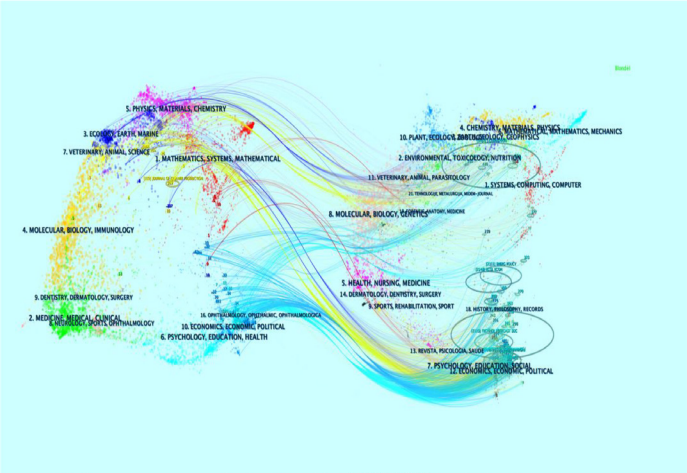

Figure 5: Dual-map overlay of environmental innovation research direction.

environmental innovation practices are listed in Table 5. With 89 publications, UTRECHT UNIVERSITY in the Netherlands tops the list, followed by the UNIVERSITY OF SUSSEX (65) and the SWISS FEDERAL INSTITUTES OF TECHNOLOGY DOMAIN (40). There are not many documents from these organizations overall. Institutional contributions play a significant role in advancing environmental innovation research. Such findings emphasize the importance of institutional support in fostering impactful environmental innovation research as confirmed by other bibliometric studies.[51-53]

The locations of the contributing organizations are displayed in Table 6. The People's Republic of China (197, 19.14%) and England (230, 14.82%) provide significantly larger contributions than any other country. However, most effective researchers in this area are affiliated with prestigious academic institutions or government agencies. Furthermore, the fact that there are groups worldwide shows that environmental innovation is a topic of interest worldwide. Rising awareness of the importance of green innovation and sustainable growth may contribute to their widespread acceptance.

Global interest in this area of study would rise, as seen in Figures 1 and 2. Despite this, new inventions for environmental sustainability have emerged in recent years, reflecting a shift in global environmental innovation. "One Belt, One Road" in China is only one example of a government program that has inspired multinational and leading firms in developing countries to form their global innovation collaboration.[54] This allows for greater visibility of empirical evidence that considers real-world, dynamic contexts. Also, the contributions of major economies like the United States, China, Germany, and the United Kingdom to environmental innovation are plain.

Table 5: Top 20 institutions contributing on the topic of environmental innovation.

Rank	Countries	Institutions	Publications
1	Netherland	Utrecht University	89
2	United Kingdom	University Of Sussex	65
3	Switzerland	Swiss Federal Institutes of Technology Domain	40
4	United Kingdom	University of London	34
5	China	Zhejiang Science and Tech University	30
6	Spain	Universidad De Castilla La Mancha	27
7	Italy	University of Ferrara	27
8	United Kingdom	University of Manchester	27
9	Sweden	Lund University	26
10	Sweden	Chalmers University of Technology	24
11	Netherland	Eindhoven University of Technology	24
12	Quebec	McGill University	24
13	France	Udice French Research Universities	23
14	Switzerland	Swiss Federal Institute of Aquatic Science Technology Eawag	22
15	France	Centre National De La Recherche Scientifique Cnrs	21
16	Netherland	Erasmus University Rotterdam	21
17	Switzerland	Eth Zurich	21
18	Australia	Monash University	20
19	Finland	Finnish Environment Institute	19
20	Germany	Fraunhofer Gesellschaft	19

Burst detection analysis of authors, sources, countries, and institutions

In order to get a sense of where the cutting-edge research is happening, it is necessary to conduct a burst analysis of authors,

Table 7: Top 10 Authors with the strongest citation bursts from 2001 to 2022.

Authors	Strength	Begin	End	2001 - 2022
Liao, Zhongju	4.61	2018	2019	
Mazzanti, Massimiliano	4.01	2009	2018	
Sovacool, Benjamin K	3.85	2019	2022	
Elliott, Kyle H	3.6	2021	2022	
Gabarrell, Xavier	2.95	2012	2014	
Kivimaa, Paula	2.71	2019	2022	
Ghisetti, Claudia	2.58	2015	2017	
Cainelli, Giulio	2.57	2012	2015	
Hekkert, Marko	2.48	2015	2015	
Scarpellini, Sabina	2.37	2019	2019	

Table 8: Top 10 Cited journals with the strongest citation bursts from 2001 to 2022.

Cited Journals	Strength	Begin	End	2001 - 2022
J ENVIRON ECON MANAG	21.85	2007	2014	
ENVIRON RESOUR ECON	19.68	2005	2017	
J ECON PERSPECT	19.31	2004	2014	
ENERGY RES SOC SCI	16.76	2020	2022	
REV ECON STAT	15.67	2003	2014	
ECOL ECON	14.53	2005	2014	
BUSINESS STRATEGY EN	14.42	2009	2018	
IND CORP CHANGE	12.68	2012	2016	
J ECON LIT	12.65	2004	2014	
EUROPEAN ENV	11.83	2012	2018	

Table 9: The top 5 countries/institutions with the strongest citation bursts from 2001 to 2022.

Countries	Strength	Begin	End	2001 - 2022
USA	8.64	2003	2014	
Spain	7.92	2012	2014	
Italy	6.33	2012	2014	
Japan	6.27	2005	2017	
France	6.21	2004	2015	
Germany	4.95	2005	2005	
Institutions	**Strength**	**Begin**	**End**	**2001 - 2022**
Univ Ferrara	5.79	2012	2018	
Zhejiang Sci Tech Univ	4.6	2018	2019	
Univ Padua	3.8	2012	2015	
Univ Sussex	3.36	2018	2020	
McGill Univ	3.24	2021	2022	
Delft Univ Technol	3.19	2015	2018	

sources, countries, and institutions to see which entities are mentioned the most frequently in a brief amount of time.[55] Table 7 shows the top ten authors from 2001 - 2020 with the highest citation burst. With a burst strength of 4.61, Liao, Zhongju has more citations than any other author, followed by Mazzanti, Massimiliano (4.01), Sovacool, Benjamin K (3.85), and Elliott, Kyle H (3.6). From 2009 to 2018, Mazzanti, Massimiliano also has the longest citations on environmental innovation from 2009 to 2018, demonstrating their importance to the field.

From 2009 to 2018, the most significant citation increases occurred in the ten highest-ranked journals shown in Table 8. In terms of burst strength, the two most important journals are J ENVIRON ECON MANAG and ENVIRON RESOUR ECON. Throughout 2005-2017, ENVIRON RESOUR ECON experienced a sustained burst in citations. Furthermore, the appearance of these citations started in 2008, which coincides with the intense era of worldwide discourse on eco-innovation that inspired many academics to pursue in-depth study in this field. Table 9 shows the top five countries and institutions with the highest citation burst rates between 2001 and 2022. The United States ranks highest in citation burst strength at 8.64, followed by Spain (7.92), Italy (6.33), and Japan (6.27). The United States was the first country to experience citation bursts; its citizens felt the negative effects of major industrialization on the environment before the trend spread to Europe, Asia, and every other country in the world. From 2012 - 2018, citation surges were strongest at Univ. Ferrara (5.79), followed by Zhejiang Sci. and Tech (4.6).

Table 10: Most frequently used keywords in the topic of environmental innovation.

Rank	Keywords	Frequency
1	Environmental Innovation	666
2	Eco-Innovation	335
3	Determinants	276
4	Performance	270
5	Management	260
6	Innovation	216
7	Policy	213
8	Sustainability	211
9	Impact	204
10	Empirical Evidence	200
11	Research and Development	189
12	Sustainability Transitions	185
13	Green Innovation	160
14	Governance	141
15	Technology	127
16	Systems	116
17	Green	113
18	Transitions	108
19	Energy	106
20	Dynamics	104

Keyword analysis

Co-word is a form of content analysis that captures scientific field maps through document keywords.[56] The ideas behind the words can be derived based on the frequency with which they appear in the document. Co-word allows researchers to use the document's content to record co-occurrence associations for the structure. Sometimes, visualization tools represent the complex relationships inside a network so they can be understood more easily. VOSviewer was considered for this analysis due to its high-quality display of diagrams.

Co-occurrence analysis

The direction of research and the overarching subject of a field can be derived from examining the co-occurrence of keywords. Therefore, we imported our data into the VOSviewer to get a visual map of keyword co-occurrence based on the generated keyword information. After extracting 5759 keywords (author keywords and keywords plus), a minimum requirement of appearing more than five times was applied to determine which terms would be included in the visualization map. As can be seen in Table 10, a total of 499 keywords were rated over the minimum and were then color-coded into nine distinct groups. There are 666 occurrences of environmental innovation, 335 of eco-innovation, 276 of determinants, 270 of performance, and 260 of management. These findings suggest that environmental innovation, eco-innovation, determinants, performance, and management are at the forefront of this field's most exciting developments.

The five most dominant color groups are shown in Figure 6: "environmental innovation" and "eco-innovation" is at the heart of Cluster 1 (blue). Cluster 2 (green) is anchored by the term "determinants" and "research and development." At the heart of our third (red) cluster are "innovation and sustainability." "Corporate social responsibility" and "knowledge" are at the heart of Cluster 4's (yellow) focus areas. The term "development cooperation" is at the heart of Cluster 5 (purple).

In order to illustrate the temporal distribution of keywords across classifications, Figure 7 provides an overlay of the co-occurrence network of keywords. A keyword's average publication year determines the range of saturation. If the publishing year is darker, it was published earlier, and if it is lighter, it was published more recently. Figure 7 displays that the research directions span 2017–2020, with most publications focusing on the research directions from 2019. These results can be seen in the yearly publications.

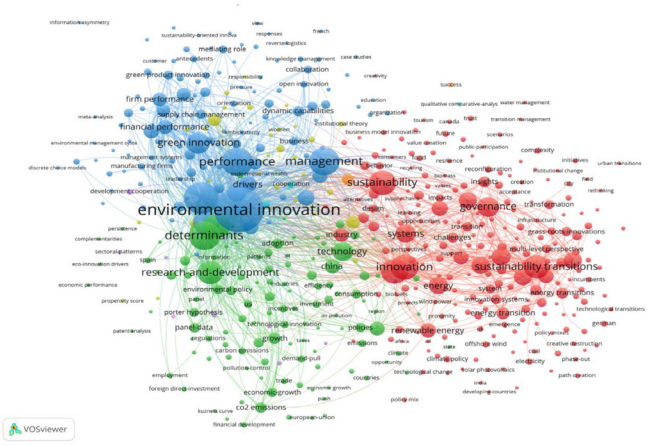

Figure 6: Co-occurrence network of keywords (network visualization).

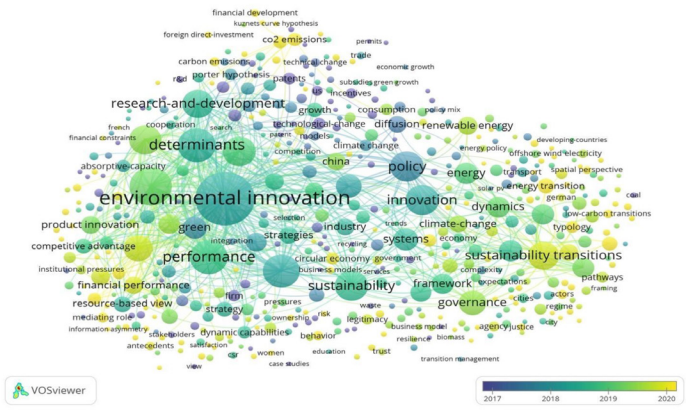

Figure 7: Co-occurrence network of keywords (overlay visualization).

Table 11: Top 20 keywords with the strongest citation bursts in the field of environmental innovation.

Keywords	Strength	Begin	End	2001 – 2022
Environmental Innovation	9.77	2001	2013	
Competitiveness	8.14	2009	2017	
Determinant	7.23	2011	2015	
Energy Transition	6.8	2020	2022	
Transition	6.79	2015	2016	
Diffusion	5.54	2009	2016	
Instrument	5.23	2010	2016	
Incentive	4.86	2010	2013	
Perspective	4.85	2015	2017	
Technological Change	4.76	2013	2016	
Environmental Management	4.45	2003	2015	
Environmental Regulation	3.91	2016	2017	
Sustainable Innovation	3.85	2019	2022	
Environmental Innovation	3.84	2013	2017	
Technology	3.8	2012	2013	
Evolution	3.75	2015	2017	
Future	3.69	2019	2020	

Burst detection analysis of keyword

Using the CiteSpace burst term detection feature, we looked into how research on environmental innovations has developed over time. The findings show that, before 2001, keywords citation burst was rare. Accordingly, we limited the search to publications and then identified the top 20 keywords with the highest citation burst from 2001 to 2022 (see Table 11). At 9.77, the keyword "environmental innovation" showed the strongest burst strength and the earliest outbreak in 2001. Both "competitiveness" and "diffusion" appeared on the list early in 2009, and both quickly rose to prominence as "burst keywords" in the published papers. We found that most terms had a burst duration of more than two years, with "environmental innovation" and "environmental management" displaying the longest burst duration of 12 years. Over the past few years, concepts like "energy transition" and "sustainable innovation" have risen to prominence as the new frontiers and major achievements of public research.

Timeline visualization

A field's progress might also be reflected in its keywords. To trace the history of environmental innovation and identify emerging patterns, we used the CiteSpace tool to run a timeline analysis on keywords from 2001 to 2020. Figure 8 shows 11 specific term

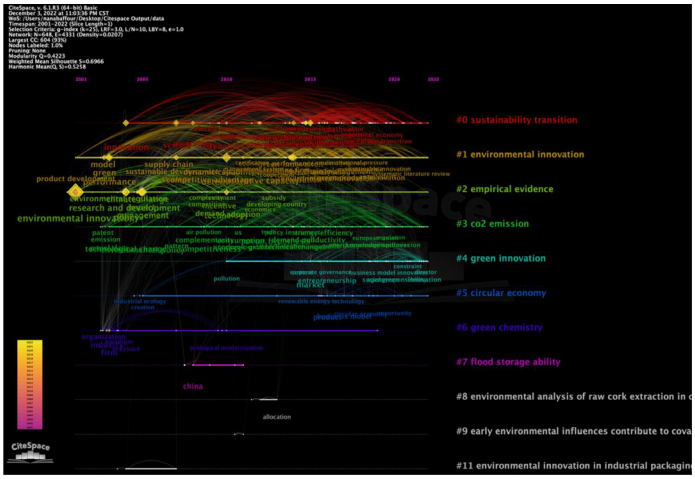

Figure 8: Timeline view of keywords from 2001 to 2022.

clusters visualized as a timeline. When the clustering process was complete, the log-likelihood clustering approach was used to assign labels to each cluster. Timeline keyword clusters are ordered by when their respective keywords first emerged. The curve of connectivity in the illustration represents the symbiotic interactions between the keywords.[57]

Cluster #0, "sustainable transition," contains papers from around 2005 to 2022 (as depicted in Figure 8). As a result of the gravity of the global sustainable development targets, the term "sustainability transition" has gained widespread acceptance. "Environmental innovation in industrial packaging" follows "environmental innovation" and then "empirical evidence," "co2 emission," "green innovation," "the circular economy," "green chemistry," "floored storage ability," "environmental analysis," and "early environmental influences."

First, environmental innovation has been a research trend and hot area for quite some time, as designated by the persistence of cluster #1. The lifespan of cluster #9 is the shortest, concluding in 2012. Research in the area of environmental innovation is concentrated on Clusters #0, #1, #3, and #4, and this trend is expected to continue for some time.

DISCUSSION

Environmental innovation is a critical area of research and practice, encompassing the development and implementation of new technologies, strategies, and processes to address environmental challenges and promote sustainability. This bibliometric review aims to examine the key findings and trends in the literature on environmental innovation from 1985 to 2022. The review synthesizes various empirical studies from web of science core collection to provide a comprehensive understanding of the subject's evolution and impact on society and the environment using VOSviewer and CiteSpace.

The study's findings indicate a continuous rise in the number of publications, indicating an increasing scholarly focus on environmental innovation in recent times. Scholars have shown significant interest in enhancing the productivity and citation impact of environmental innovation research, highlighting the growing importance of addressing environmental challenges through innovative approaches. These results are in line with the findings of Šūmakaris and Korsakienė,[6] who observed a similar trend of growing interest and publication output in the field of eco-innovation strategies, particularly in the last five years. Additionally, various other research works have confirmed that articles constitute the majority of research documents in this area.[6,58-60]

Furthermore, environmental innovation serves as a multidisciplinary domain that draws researchers from diverse fields. The adoption of an interdisciplinary approach highlights the intricate nature of environmental challenges and underscores the necessity for collaborative endeavors to effectively address them. A pertinent study conducted by Albort-Morant, Henseler[8] focused on green innovation and revealed that scholars from various disciplines, such as management, economics, engineering, and biology, are actively engaged in exploring this topic. This reflects the substantial interest that environmental innovation has garnered in the current research landscape, as evident from analyses of research areas and document sources. Consistent with other studies in the field of innovation,[7,61] the top publications in this study align with prevailing trends.

Moreover, various empirical studies have delved into the geographic and institutional distribution of environmental innovation research, pinpointing key countries and institutions actively engaged in this field. Notably, the research consistently identifies China, Europe, and the United States as the regions with the most influential authors and publications.[7,59,62] These findings align with the results of our present study. Furthermore, our research brings to light an encouraging trend of an increasing number of papers originating from scholars in Asia, particularly China, indicating a rising interest and significant contributions to environmental innovation research from this region. As social demand, governmental regulations, and subsidies geared toward reducing environmental impact continue to escalate in contemporary industries, we posit that the interest in environmental innovation is bound to witness constant growth. This is further supported by the exponential surge in scientific publications in recent years, transcending geographical boundaries and encompassing various countries.

In recent years, environmental innovation research has witnessed a shift in focus, encompassing various emerging areas and subjects. Several empirical studies have been conducted to identify the key drivers behind environmental innovation.[63-65] A comprehensive survey of the literature on environmental innovation was carried out by Barbieri *et al*,[9] utilizing main path analysis. Their research

revealed that the literature on environmental innovation revolves around four main themes: determinants of EI; economic effects of EI; environmental effects of EI; and policy inducement in EI. Interestingly, these findings align with the results of our current study, as evident from the keyword and timeline analyses. This alignment highlights the ever-evolving nature of environmental innovation and underscores the importance of addressing the changing environmental challenges. Policymakers and practitioners can utilize these valuable insights to design effective strategies and policies that foster environmental innovation practices.

This empirical and bibliometric literature review provides a comprehensive overview of the research on environmental innovation. The analysis revealed increasing academic interest in the field, the multidisciplinary nature of environmental innovation research, and the significant contributions of scholars from different regions. The review also identified emerging focus areas and determinants that shape environmental innovation initiatives. Policymakers, researchers, and practitioners can utilize the insights gained from these empirical studies to drive sustainable solutions and address pressing environmental challenges effectively.

CONCLUSION

In the study, we provided a detailed analysis of the literature on environmental innovation from 1985 to 2022. We analyzed the features of articles published in this area from various viewpoints using VOSviewer and CiteSpace.

There has been and continues to be, a rise in academics from all walks of life interested in studying environmental innovation. In this study, 1552 relevant documents were methodically gathered and analyzed through bibliometrics.

Publications and citations of all 1552 documents show that academic interest in environmental innovations has increased. If we consider publications on environmental innovation, the most widely cited publication is in the environmental sciences ecology field.

A dual-map overlay of journals shows that many research articles have been written about economics, education, sociology, and psychology. Most influential authors come from China, Europe, and the United States; among them are Liao ZJ and Mazzanti M, both of whom are highly published and cited researchers. Increasing numbers of papers have been published in recent years by scholars in Asia, particularly China. Influencing scientists from all around the globe are interested in studying the topic of environmental innovation. The University of Utrecht stands out as the most fruitful establishment. The University of Ferrara has the highest citations per publication in the field of environmental innovation, further demonstrating its leadership in the field.

Our in-depth examination of these three facets of keywords allowed us to uncover trending subjects that shift over time. Co-occurrence analysis showed that environmental innovation, eco-innovation, determinants, and performance are the key areas of concentration in the most productive research hubs. Detecting and analyzing bursts revealed that environmental innovation, competitiveness, and determinants have emerged at the forefront of public research and the most recent breakthroughs in the field. According to the timeline analysis, sustainability transition and environmental innovation are still important in environmental innovation research. There is much room for, and the possibility for, new developments in environmental innovation research.

Limitations and suggestions for future research directions

This study has some drawbacks, even though it does produce some intriguing findings.[66] That being said, some promising avenues for future research need to be explored. First, extracting all relevant data from bibliometric maps produced by keyword network analysis is challenging. It is possible to incorporate keywords, titles, abstracts, and even whole texts for a deeper dive into a topic. To gain insights into this knowledge base future attempts to review the current state of environmental innovation literature may employ different approaches, such as content analysis,[67] to get insights into this knowledge base. Second, we solely used Web of Science documents in our sample. Although the Web of Science contains more scientific publications than any other database, some papers may still be missing. In the future, it would be more persuasive if researchers could search across multiple databases, such as Scopus, Semantics, Dimension, and Lens. Last, whatever the sources of the studies, this review includes them all. Consequently, it could give a global perspective of environmental innovation literature but lacks a specialization corresponding to distinct countries or areas. Researchers who wish to provide deeper insights into the environmental innovation literature in the future may wish to consider the regional method.[68,69]

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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