RELATIONSHIP BETWEEN ECO-INNOVATION AND ENVIRONMENTAL PERFORMANCE: BIBLIOMETRIC ANALYSIS AND VISUALIZATION ANALYSES

Ahmet YURTERİ
domadez9@gmail.com

Sıla YURTERİ
syurteri1283@gmail.com

Assoc. Prof. Dr. Azmiye YINAL
azmiye.yinal@akun.edu.tr

ABSTRACT
Eco-innovation is defined as the discovery and development of innovative practices by businesses to solve environmental problems. With this aspect, eco-innovation contributes to the reduction of costs and environmental pollution in the long term. The aim of this study is to examine the relationship between eco-innovation and environmental performance through bibliometric analysis and visualization methods. Biblioshiny and VOSviewer programs were used to perform the analysis. According to the results of the analysis, it has been determined that the interest in Eco-Innovation and Environmental Performance studies has accelerated since 2021, the journal with the highest number of studies is the Journal of Cleaner Production, the author with the highest number of on the subject is Cai Li, the institution with the highest number of studies is Jiangshu University, the country with the highest number of studies on the subject is China, the most mentioned keywords other than eco-innovation and environmental performance are sustainability, sustainable development, financial performance, economic performance.
Keywords: Eco-Innovation, Environmental Performance, Sustainability Bibliometric Analysis, Visualization Analysis

INTRODUCTION

Eco-innovation refers to new ideas, behaviors, products, or processes that reduce environmental impacts or resource use, whether intentional or not (Diaz-Garcia et al., 2015). Eco-innovation is a business strategy that encourages green creativity and the development of environmentally friendly products and services (Ilic et al., 2022). Eco-innovation is a strategy that provides customer and business values in order to reduce the negative impact of industrial activities on the environment and promote sustainable development (Kuo & Smith, 2108). Accordingly, the main drivers of eco-innovations can be grouped as external and internal drivers (Passaro et al., 2023). The external drivers of eco-innovation in organizations include environmental regulations, competitive pressures, and customer demands for environmentally friendly products and services (Cai & Li, 2018). The internal drivers of eco-innovation in organizations include institutional capabilities, technological capabilities, and corporate social responsibility (Salim et al., 2019). Effective knowledge management is essential in building organizational capabilities and enhancing workforce creativity for developing environmentally friendly products and services (Wang et al., 2022). Data-driven talent management practices can be adopted to enhance technological capabilities and ensure continuous business process improvement for eco-innovation performance (Munodawafa & Johl, 2019). The corporate social responsibility strategy to promote eco-innovation in organizations is channeled through the creation of employee green consciousness exhibited through employee green behaviors and managerial environmental awareness reflected through pro-environmental behaviors at the corporate level (Peng & Liu, 2016). Eco-innovation refers to the pursuit of innovation in various environmental areas such as emission reduction, recycling, and material substitution (De Jesus et al., 2018). It goes beyond the mere adoption of eco-innovation and focuses on the extent to which firms' activities benefit the environment (Bossle et al., 2016). Eco-innovation can positively impact society by addressing social challenges such as access to clean water, sanitation, and affordable clean energy (Park et al., 2017). Eco-innovation can promote inclusive growth and improve the quality of life by providing sustainable solutions to societal needs (Dogaru, 2020). Therefore, eco-innovation is of increasing importance for research and policy-making aimed at optimizing natural resource use and reducing the ecological footprint (Hassan et al., 2023). Firms have traditionally not been structured to integrate environmental aspects into their internal domains, thus facing the liability of innovation (Hellström, 2007). While well-defined environmental regulations encourage eco-innovation in companies, resulting in higher productivity, eco-innovation patents are becoming increasingly important as market opportunities (Oltra et al., 2010).

The value of the company cannot be increased only by good financial successes, the company should also pay attention to the social, economic and environmental impacts of the company's activities, such as pollution and the effects of the company's production process activities (Alsayegh et al., 2020). Therefore, companies should be more effective and efficient in the use of company resources for the continuity of the company's current and future activities (Tammineedi, 2010). The main reason for improving the environmental performance of the company is

the increasing and unmet demands from stakeholders (Azzone & Manzini, 1994). Eco-innovation offers innovative solutions that aim to improve environmental performance by reducing the environmental impacts of businesses (Costantini et al., 2017). This relationship is based on factors such as resource efficiency, waste and emission reduction, legal compliance and consumer preferences (Sumrin et al., 2021). Eco-innovations increase energy efficiency and reduce carbon footprint, while at the same time becoming attractive to environmentally conscious consumers (Paparoidamis & Tran, 2019). Thus, environmental performance increases and contributes to sustainability goals (Carchano et al., 2024).
The aim of this study is to examine the relationship between eco-innovation and environmental performance through bibliometric analysis and visualization methods.

METHODOLOGY

Bibliometric Analysis

Bibliometric analysis serves as a valuable tool to evaluate the characteristics of a particular field of study (Salinas-Ríos, 2022). Bibliometric methods primarily aim to identify literature flows within a broad or more specialized subject area through content and citation analysis of scientific publications (Gan et al., 2022). While alternative methods such as literature reviews can be used to search, organize, and synthesize scientific production in a specific subject area, the strength of the bibliometric approach lies in its systematicity and transparency, as well as its ability to reveal relational, structural, and temporal aspects of established or emerging research streams (Marzi et al., 2024). Various software applications are available to perform bibliometric analyses, such as VOSViewer, SATI, HistCite, and CiteSpace (Geng et al., 2024).
In this study, articles on the themes of eco-innovation and environmental performance were selected. Web of Science database was used as data sources. VOSviewer and Biblioshiny were used for data analysis. Citation analysis and key analysis were performed in the study. First, keyword selections and combinations were determined in the study, and the relevant keywords were used in the search engine. In the search engine, the combination of “eco innovation” and “environmental performance” or “green innovation” and “environmental performance” or “green stage innovation” and “environmental performance” or “green product innovation” and “environmental performance” was used. Then, the studies were filtered to be English and articles. As a result of the combinations, 714 articles were reached, and as a result of the filtering process, 685 articles were reached.
Keyword analysis and co-citation analysis were performed using VOSviewer. It uses the VOS mapping technique to create distance-based maps using similarity matrices (Markscheffel & Schröter, 2021). VOSviewer provides visualization of knowledge maps for large-scale literature data representing authors, journals, and other related information (Cheng et al., 2021). It is widely used in bibliometric analysis research. The visualization map consists of nodes and links (Guo et al., 2021). The size of the circle of a node is proportional to the frequency of the displayed indicator (Shen et al., 2018). In cluster analysis, the color of the circle is determined by its category (Meija et al., 2021). The thickness and length of the links between nodes represent their connection strength and relevance (Donthu et al., 2021).

FINDINGS

Table 1 shows the characteristics of the articles obtained from the Wos database using specific keywords and combinations of these keywords. A total of 685 articles, 33,373 references, and 1,782 keywords were found. The first article was found in 2002. The average age of the articles is 2.57 years, which indicates that the studies on the subject are mostly recent. It is understood from the total number of authors that the majority of the studies have co-authors (2007 authors).

Table 1. Descriptive Information

Definition	Conclusion
Time period	2002:2024
Number of Articles	685
Average Age of Articles	2.57
Average Number of Citations of Articles	37.95
Number of References	33373
Number of Keywords	1782
Number of Authors	2007
Number of Single Author Articles	39

Figure 1 shows the distribution of studies examining the relationship between eco-innovation and environmental performance over the years. When evaluated in general, it can be said that the studies have increased steadily over the years. According to the figure, it is seen that the interest in these studies has accelerated since 2021. The

widespread environmental sensitivities around the world and the governments' orientation towards such practices may have pushed researchers to conduct more research on this subject.

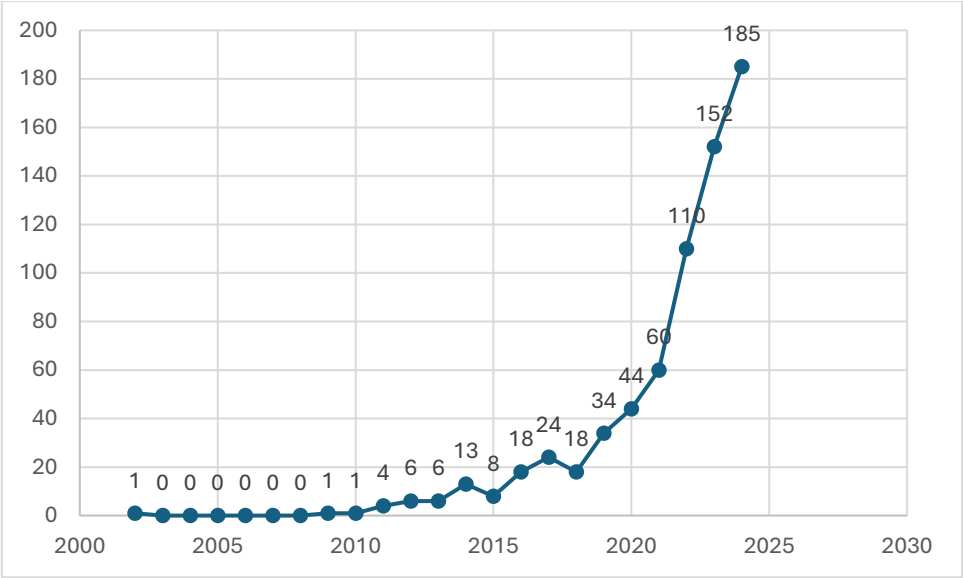

Figure 1. Distribution of Articles by Year

Figure 2 shows the journals in which eco-innovation and environmental performance articles are published the most. Accordingly, the Journal of Cleaner Production is the journal in which the most studies have been conducted on this relationship, with 77 articles. Sustainability is in second place with 72 studies, and Business Strategy and Environment is in third place. The reason why these journals are the ones with the most publications may be that they are journals that publish frequently.

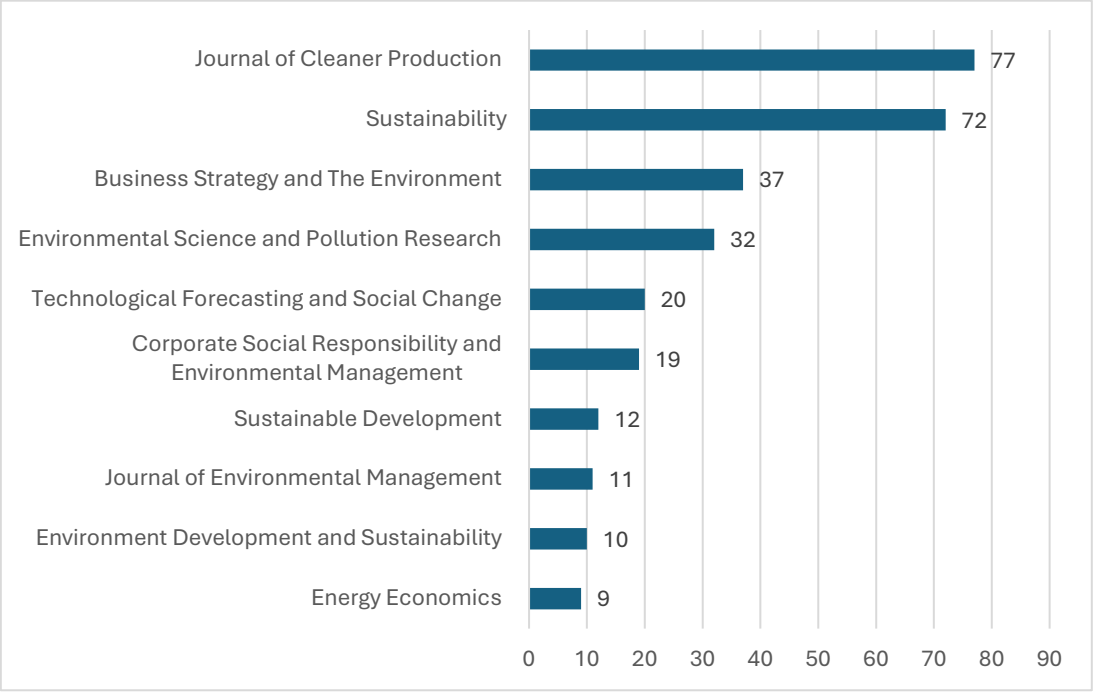

Figure 2. Featured Journals

Figure 3 shows the authors who contributed the most to the studies on the relationship between eco-innovation and sustainable performance. Accordingly, the author who has done the most studies on the subject is Cai Li with 9 articles. Adnan Khan, Qian Li, Hai-Jie Wang are in the second place with 6 articles. In his studies, Cai Li examined the relationship between energy innovation and energy pollution (Li et al. B, 2023), how green business strategies and competencies improve green innovation for firm performance (Ashraf et al., 2024), how it affects green innovation after the implementation of environmental regulations by the Chinese Government (Li et al.,

2022), how entrepreneurial SMEs increase environmental performance with green impact orientations (Khan et al., 2022), how the relationships between corporate social responsibility, green behavior of employees, green culture, environmental performance and green innovation are (Li et al. A, 2023), and how green dynamic capability affects environmental and social innovation behavior.

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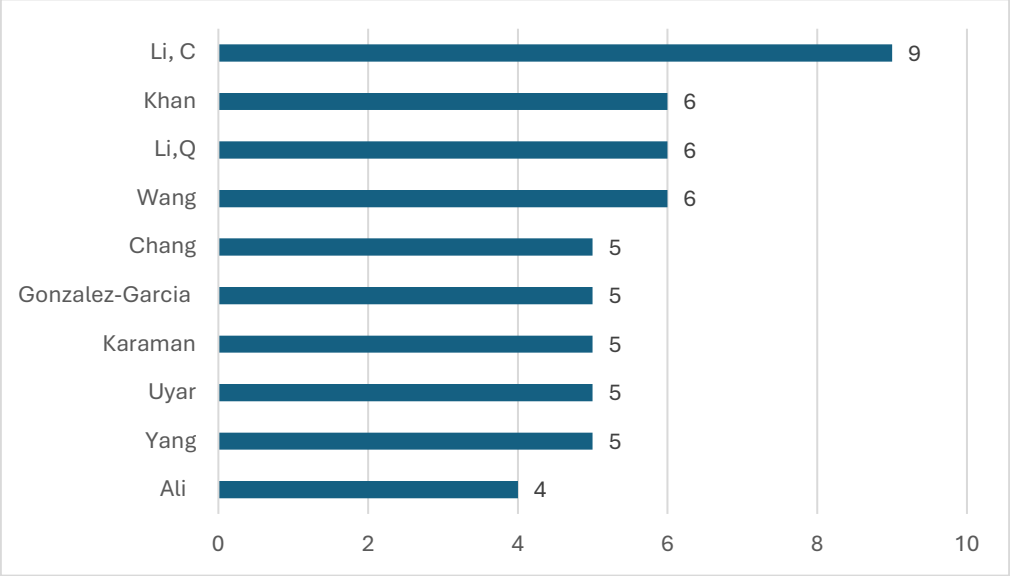

Figure 3. Featured Authors

Figure 4 shows the institutions that have published the most on the relationship between eco-innovation and environmental performance. Accordingly, the institution that has published the most studies is Jiangshu University with 27 articles, the second institution that has published the most studies is Beijing Institute of Technology with 12 articles, and the third institution that has published the most studies is Xi'an Jiatong University.

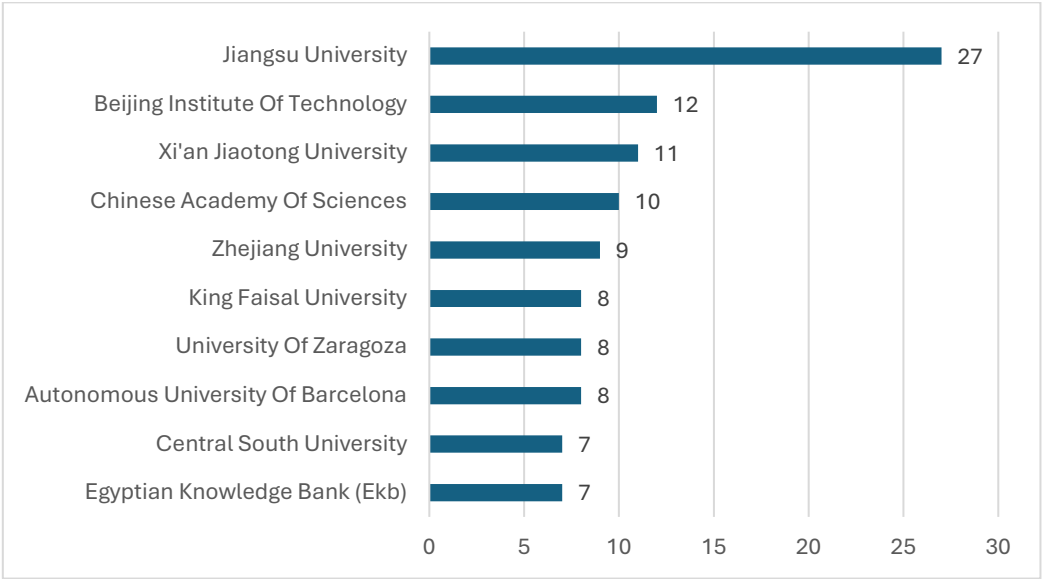

Figure 4. Featured Organizations

Figure 5 shows the countries that the articles belong to. Accordingly, the country with the most studies on the subject was China with 687 authors. China was followed by Spain with 99 authors and Pakistan with 96 authors. Based on the figure, it is possible to say that China is involved in most of the studies in this field. China may have attracted the attention of researchers as one of the countries that has problems with environmental pollution.

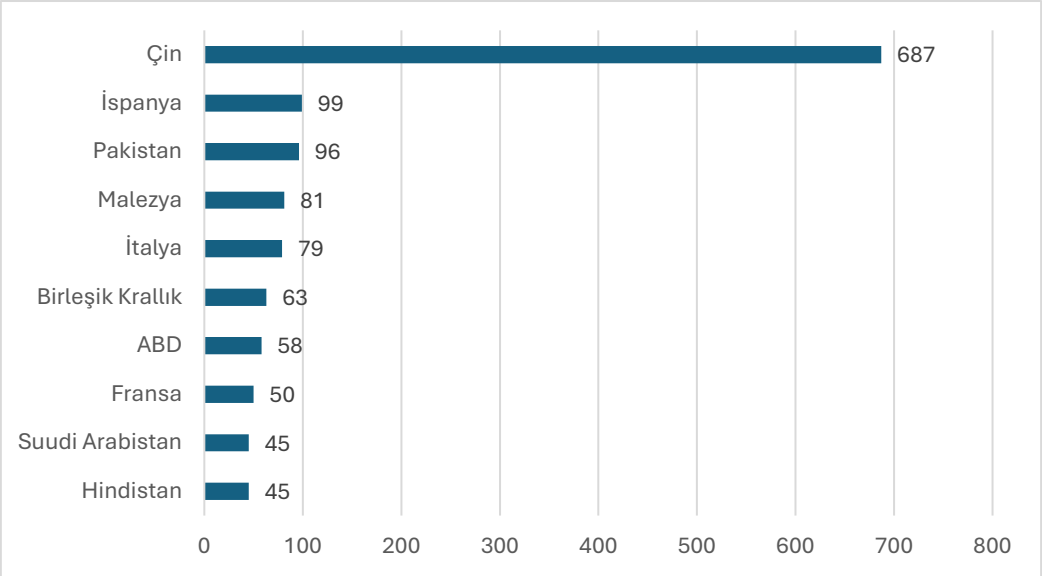

Figure 5. Featured Countries

Table 2 shows the most cited articles on the relationship between eco-innovation and environmental performance. It was determined that the most cited study was the article titled "Determinants of eco-innovations by type of environmental impact—The role of regulatory push/pull, technology push and market pull" written by Horbach et al. in 2012 with 964 citations. In this article, Horbach et al. (2012) investigated the determinants of eco-innovation. It was determined that the second most cited study was the article titled "Green innovation and environmental performance: The role of green transformational leadership and green human resource management" written by Singh et al. in 2020 with 889 citations. Singh et al. (2020) examined how green human resource management interacts with green transformational leadership, green innovation, and environmental performance. The third most cited study was the article titled "Green innovation and environmental performance: The role of green transformational leadership and green human resource management" written by Chiou et al. in 2011 with 782 citations. It was determined that the article titled "The influence of greening the suppliers and green innovation on environmental performance and competitive advantage in Taiwan" written by Chiou et al. (2011) examined the relationship between the concepts of green supply chain, green innovation, environmental performance and competitive advantage.

Table 2. Most Cited Articles

R	Magazine	TR	Average Quote	Article	Writer	Year
1	Eco-Econ	964	74.15	Determinants of eco-innovations by type of environmental impact—The role of regulatory push/pull, technology push and market pull.	Horbach et al.	2012
2	Technol Forecast Soc	889	177.8	Green innovation and environmental performance: The role of green transformational leadership and green human resource management.	Singh et al.	2020
3	Transport Res E-Log	782	55.86	The influence of greening the suppliers and green innovation on environmental performance and competitive advantage in Taiwan	Chiou et al.	2011
4	J Clean Prod	649	64.9	Green R&D for eco-innovation and its impact on carbon emissions and firm performance	Lee & Min	2015
5	Technol Forecast Soc	626	104.34	Green innovation and organizational performance: The influence of big data and the moderating role of management commitment and HR practices	Al-Qasar & Singh	2019
6	Technol Forecast Soc	554	110.8	Corporate social responsibility and environmental performance: The mediating role of environmental strategy and green innovation	Kraus et al.	2020
7	J Clean Prod	455	65	The drivers of eco-innovation and its impact on performance: Evidence from China	Cai & Li	2018

8	Bus Strategy Environ	40 8	58.29	Green innovation, managerial concern and firm performance: An empirical study	Tang et al.	2018
9	J Bus Ethics	39 6	49.5	Green innovation and performance: The view of organizational capability and social reciprocity.	Huang & Li	2017
10	Technol Forecast Soc	36 2	90.5	Analyzing the relationship between green innovation and environmental performance in large manufacturing firms	Rehman et al.	2021

Table 3 shows the keywords frequently included in eco-innovation environmental performance studies. Accordingly, the most frequently mentioned keywords, other than eco-innovation and environmental performance, were Sustainability (41 articles), Sustainable Development (38 articles), Financial Performance (31 articles), Economic Performance (29 articles).

Table 3. Most Frequently Mentioned Keywords

Words	**Frequency**
Eco Innovation	396
Environmental Performance	242
Sustainability	41
Sustainable Development	38
Financial Performance	31
Economic Performance	29
Corporate Social Responsibility	25
Company Performance	25
SME	21

Figure 6 shows the visual map of keywords in studies addressing the relationship between eco-innovation and environmental performance. Accordingly, the keywords are divided into 9 different clusters. The red cluster consisting of 14 keywords is led by sustainable development, the green cluster consisting of 13 keywords is led by sustainability, the blue cluster consisting of 9 keywords is led by the company's environmental performance, the yellow cluster consisting of 8 keywords is led by eco-innovation, the purple cluster consisting of 7 keywords is led by green human resources management, the light blue cluster consisting of 5 keywords is led by environmental performance, the orange cluster consisting of 4 keywords is led by green supply chain management, the brown cluster consisting of 4 keywords is led by economic performance, and the pink cluster consisting of 3 keywords is led by corporate social responsibility.

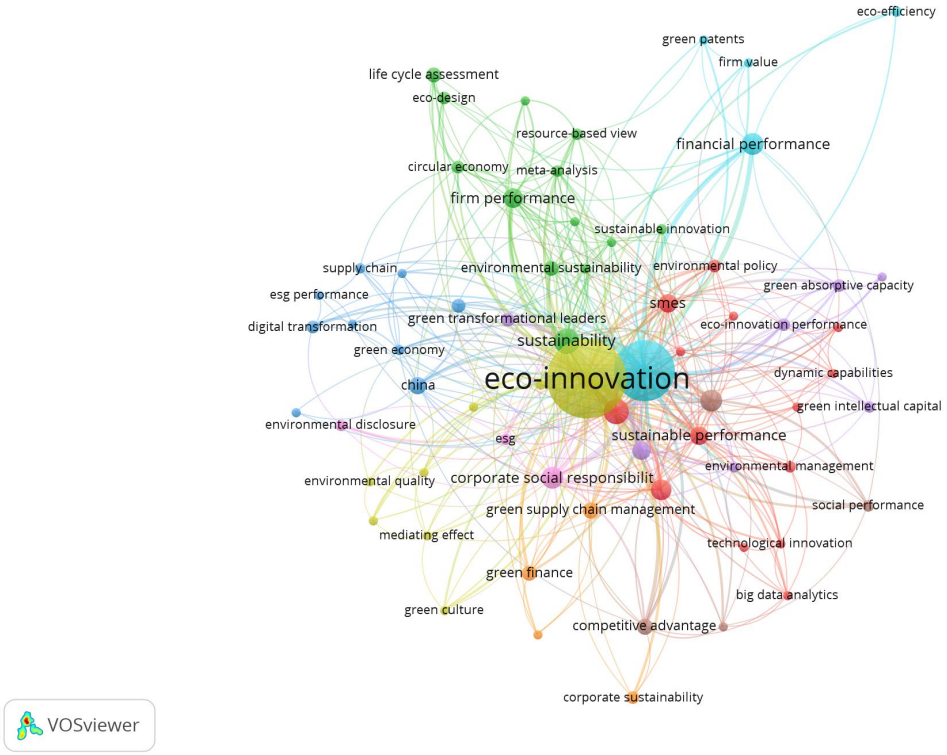

Figure 6. Keywords

Figure 6 shows the results of the co-citation analysis by reference. Accordingly, the references are divided into 4 separate clusters. The red cluster has 58 references, the green cluster has 53 references, the blue cluster has 34 references, and the yellow cluster has 26 references. The reference with the most co-citations is the study by Chen et al. (2006), which is the leader of the yellow cluster. The reference with the second most co-citations is the study by Chiou (2011), which is the second leader of the yellow cluster. The reference with the third most co-citations is the study by Singh et al. (2020), which is the leader of the green cluster. The reference with the fourth most co-citations is the study by Porter & Linde (1995), which is the leader of the red cluster. The reference with the fifth most co-citations is the study by Chen (2008), which is the second leader of the green cluster.

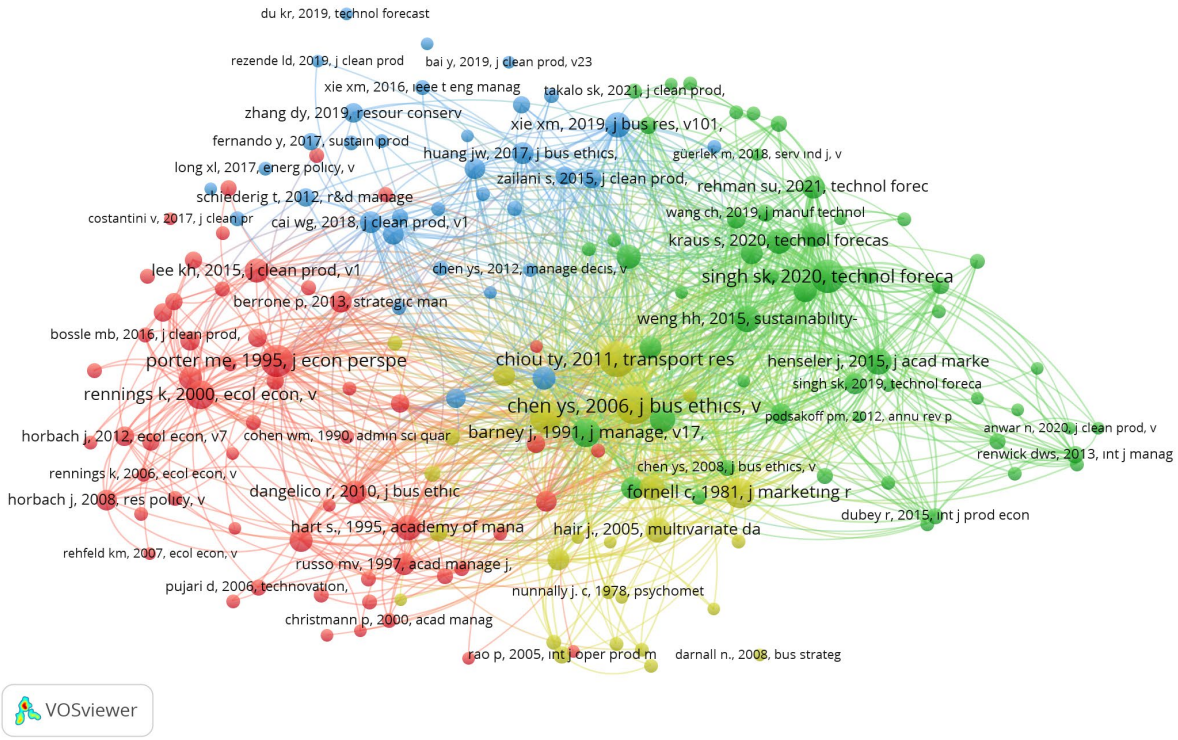

Figure 7. Co-Citation Analysis by Reference

In Figure 8, co-citation analysis was performed by journal in the articles examining the eco-innovation-environmental performance relationships. The red cluster has 102 journals. Journal of Cleaner Production is the leader of the red cluster with 5329 co-citations and 322610 total link power (ranked 1st). Ecological Economics is the second leader of the red cluster with 814 co-citations and 51777 (ranked 10th). Environmental Science and Pollution Research is the third leader of the red cluster with 721 co-citations and 46597 total link power (ranked 12th). Research Policy is the fourth leader of the red cluster with 640 co-citations and 43307 total link power (ranked 13th). Journal of Environmental Management is the fifth leader of the red cluster with 636 co-citations and 43129 total link power (ranked 14th). This cluster focuses on topics such as environmental management and environmental economics.

The green cluster has 92 journals, Business Strategy Environment is the leader of the green cluster with 2199 co-citations and 163294 total link strength (ranked 2nd). Sustainability is the second leader of the green cluster with 1589 co-citations and 107549 total link strength (ranked 4th). Technological Forecasting and Social Change is the third leader of the green cluster with 1272 co-citations and 93646 total link strength (ranked 5th). Journal of Business Research is the fourth leader of the green cluster with 855 co-citations and 66894 total link strength (ranked 7th). Corporate Social Responsibility and Environmental Management is the fifth leader of the green cluster with 826 co-citations and 61419 total link strength (ranked 8th). This cluster includes environmental studies.

The blue cluster has 59 journals and the Journal of Business Ethics is the leader of the blue cluster with 1734 co-citations and 128386 total link strength (ranked 3rd). Strategic Management Journal is the second leader of the blue cluster with 928 co-citations and 70291 total link strength (ranked 6th). The Academy of Management Journal is the third leader of the blue cluster with 624 co-citations and 47573 total link strength (ranked 11th). The Academy of Management Review is the fourth leader of the blue cluster with 446 co-citations and 35712 total link strength (ranked 16th). Journal of Financial Economics is the fifth leader of the blue cluster with 305 co-citations and 19773 total link strength (ranked 24th). This cluster focuses on financial economics and business.

The yellow cluster has 57 journals, International Journal of Production Economics is the leader of the yellow cluster with 743 co-citations and 56482 total link power (ranked 9th). Journal of Operations Management is the second leader of the yellow cluster with 328 co-citations and 26178 total link power (ranked 19th). International Journal of Operations & Production Management is the third leader of the yellow cluster with 310 co-citations and 24195 total link power (ranked 21st). International Journal of Production Research is the fourth leader of the yellow cluster with 285 co-citations and 21977 total link power (ranked 23rd). Transportation Research Part E: Logistics and Transportation Review is the fifth leader of the yellow cluster with 247 co-citations and 17951 total link power (ranked 28th). This cluster focuses on topics such as logistics, production management, operations management.

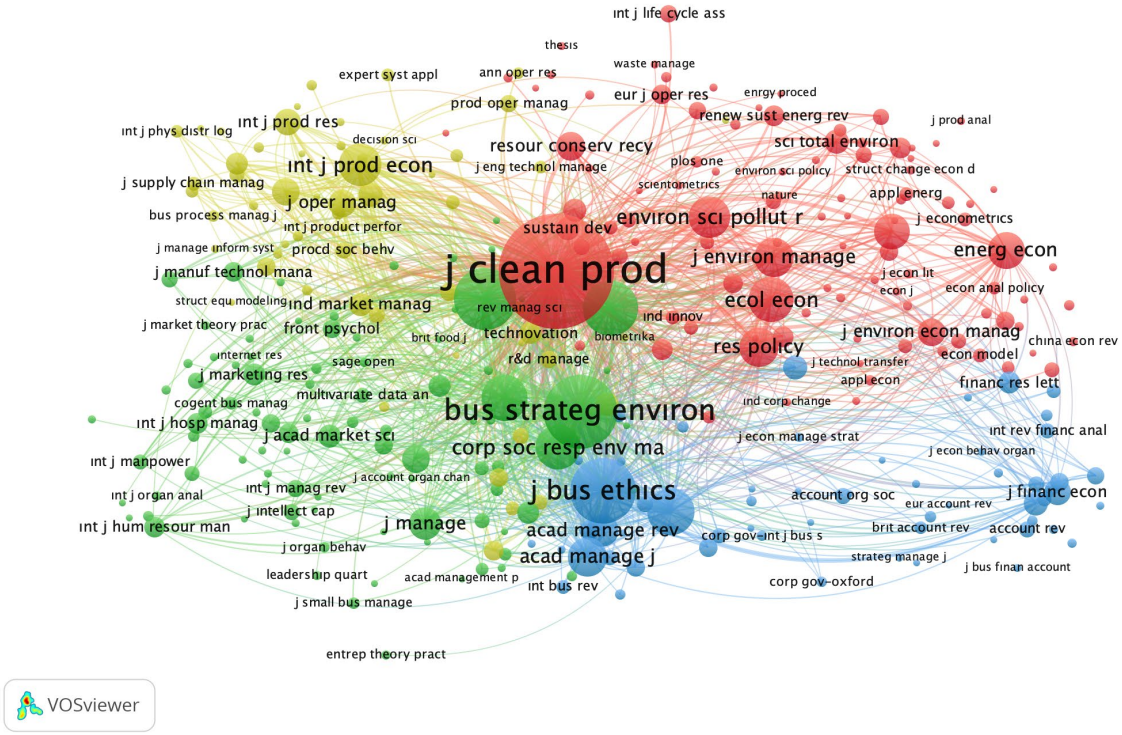

Figure 8. Co-Citation Analysis by Journal

In Figure 9, co-citation analysis was performed by author in the articles examining the eco-innovation-environmental performance relationships. The authors are divided into 4 clusters. The red cluster consists of 99 authors. The leader of this cluster is Xie et al. (2019) with 147 co-citations and 4464 total link power (ranked 11th). Li et al. (2018) is the second leader of the red cluster with 114 co-citations and 3409 total link power (ranked 19th). Berrone et al. (2013) is the third leader of the red cluster with 95 co-citations and 2746 total link power (ranked 28th). This cluster focuses on the role of environmental regulations in the relationship between eco-innovation and environmental performance, and the relationship between eco-innovation and firm performance. Xie et al. (2019) examined the relationship between green product innovation, green process innovation and the financial performance of a firm. Li et al. (2018) investigated the impact of environmental legitimacy on corporate carbon disclosure and examined its role as a mediator of green innovation . Berrone et al. (2013) examined the impact of greater regulatory and normative pressures regarding environmental issues on firms' propensity to engage in environmental innovation.

The green cluster has 92 authors. Porter & Linde (1995) is the leader of the green cluster with 294 co-citations and 7797 total link strength (ranked 3rd). Hart (1995) is the second leader of the green cluster with 169 co-citations and 5295 total link strength (ranked 7th). Rennings (2000) is the third leader of the green cluster with 165 co-citations and 4294 total link strength (ranked 12th). This cluster focuses on the theoretical explanation of studies on eco-innovation and environmental performance. Porter & Linde (1995) examined the relationship between environmental regulation and competitiveness. Hart (1995) proposed a natural resource-based view of the firm, a theory of competitive advantage based on the firm's relationship with the natural environment. Rennings (2000) examined the contribution of eco-innovation research to ecological economics by redefining innovation.

The blue cluster has 77 authors. Chen (2008) is the leader of the blue cluster with 515 co-citations and 15871 total link strength (Ranked 1). Hair et al. (2011) is the second leader of the blue cluster with 267 co-citations and 8514 total link strength (Ranked 2). Singh et al. (2020) is the third in the blue cluster with 193 co-citations and 6282 total link strength (Ranked 5). This cluster focuses on studying the structural equation model on eco-innovation. Chen (2008) proposed a new structure to investigate green innovation and its positive effects on firms' green image. Hair et al. (2011) conducted a research on the conditions under which PLS-SEM models can be used. Singh et al. (2020) examined how green human resource management affects the links between green transformational leadership, green innovation, and environmental performance.

The yellow cluster has 53 authors. Zhu et al. (2012) is the leader of the yellow cluster with 249 co-citations and 7407 total link strength (ranked 4th). Chiou et al. (2011) is the second leader of the yellow cluster with 156 co-citations and 4940 total link strength (ranked 8th). Chang & Chen (2013) is the third leader of the yellow cluster

with 127 co-citations and 4802 total link strength (ranked 9th). This cluster focuses on green supply chain management practices. Zhu et al. (2012) investigated how organizations adopt green supply chain management innovation practices and whether this adoption affects their performance. Chiou et al. (2011) investigated how green supply chain and green innovation affect environmental performance. Chang & Chen (2013) examined the positive effect of green organizational identity on green innovation performance.

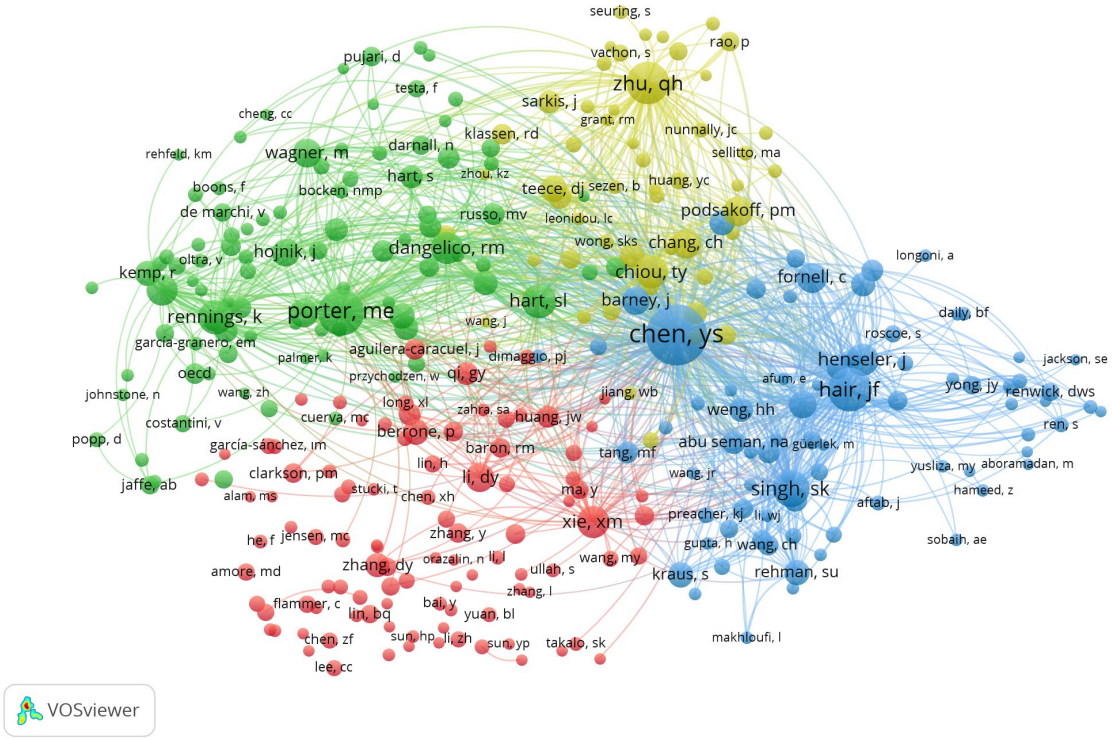

Figure 9. Co-Citation Analysis by Author

CONCLUSION

In this study, a bibliometric analysis of studies on the relationship between eco-innovation and environmental performance was performed. The Web of Science database was used for this process. As a result of the relevant keyword combinations and filtering process, a total of 685 articles, 33373 references, and 1782 keywords were reached. According to the articles obtained, it was determined that the interest in these studies has increased rapidly since 2021, the journal with the most studies was Journal of Cleaner Production, the author who has done the most studies on the subject was Cai Li, the institution with the most studies was Jiangshu University, the country with the most studies on the subject was China, the most cited study was the article titled "Determinants of eco-innovations by type of environmental impact—The role of regulatory push/pull, technology push and market pull" written by Horbach et al. in 2012, and the most mentioned keywords other than eco-innovation and environmental performance were sustainability, sustainable development, financial performance, and economic performance. In the co-citation analysis performed by reference, it was determined that the studies of Chen et al. (2006), Chiou (2011) and Singh et al. (2020) had the most co-cited references. In the co-citation analysis performed by journals, the journals were divided into 4 clusters. Journal of Cleaner Production is the leader of the red cluster. The journal Business Strategy Environment leads the green cluster . The journal Journal of Business Ethics leads the blue cluster . The journal International Journal of Production Economics leads the yellow cluster.

As a result of the co-citation analysis carried out according to the authors, the authors were divided into 4 clusters. The leader of the red cluster is Xie et al. (2019) and focuses on the role of environmental regulations in the relationship between eco-innovation and environmental performance and the relationship between eco-innovation and firm performance. Porter & Linde (1995) is the leader of the green cluster and focuses on the theoretical explanation of studies on eco-innovation and environmental performance. Chen (2008) is the leader of the blue cluster and focuses on structural equation model studies on eco-innovation. Zhu et al. (2012) is the leader of the yellow cluster and focuses on green supply chain management practices.

In this study, Web of Science database was used. A broader perspective can be provided by using various databases and industry reports. In-depth analyses can be made with case studies and surveys on the subject. Eco-innovation practices and environmental performance policies in different regions may differ in cultural and legal frameworks.

Researchers can conduct regional studies on the subject. Specific industries can be studied to analyze the effects of eco-innovation on sectors.

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