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Review Article

Decade of Green Innovation Research: Tracing the Intellectual Structure and Emerging Trends

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Abstract

This paper analyzes 3,931 publications on green innovation (2010–2023) using VOSviewer bibliometric software. Results reveal that while China dominates publication volume, Germany and Taiwan are more frequently cited, indicating higher research impact. Thematic analysis identifies three core research clusters: eco-innovation and environmental policy; management and technological aspects of green innovation; and sustainable business models with industry applications. These clusters reflect the field's multidisciplinary nature, integrating environmental economics, corporate sustainability, and innovation management perspectives. Co-citation analysis highlights the central role of the Journal of Cleaner Production, Renewable & Sustainable Energy Reviews, and Resources, Conservation & Recycling. Temporal keyword analysis reveals a significant shift in research focus: early studies emphasized foundational concepts like eco-innovation and corporate social responsibility (CSR), while recent work prioritizes urgent issues including carbon emissions, renewable energy, and green finance. The analysis demonstrates that green innovation research increasingly emphasizes macroeconomic and regulatory dimensions, particularly in developing countries. This work offers valuable insights for future research, identifying financial strategies, policy frameworks, and localized implementations as priority areas for investigation.

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INTRODUCTION

Everyone is talking about going green right now, which is why green innovation is blowing up in both research and industry. It's not just about building better tech. It's actually a multidimensional construct that blends technological advancement, environmental sustainability, and social responsibility right into how a company operates.

We notice people often swap the terms "green innovation" and "eco-innovation" like they're the same thing, while they are conceptually distinct. If you look at eco-innovation, it's a narrower subset. It focuses almost entirely on boosting environmental performance—think cutting carbon emissions, squeezing more out of resources, or preventing pollution (Oduro, 2024). Green innovation encompasses a much broader spectrum. We tend to think of it as the whole package because it loops in technological novelty and social value creation alongside those green outcomes (Ahmed et al., 2023). For our bibliometric analysis, getting this boundary right is absolutely critical. That's why we're adopting the broader green innovation definition, though we absolutely acknowledge eco-innovation as a massive sub-domain inside it.

To ground this, we looked at the Oslo Manual (OECD/Eurostat, 2018). They define standard business innovation as introducing a new or significantly improved product or process to generate economic value. Simple enough, right? Well, green innovation stretches that definition by making environmental and social value core objectives right alongside making economic contributions (OECD/Eurostat, 2018). While normal innovation just wants market competitiveness and financial returns, green innovation forces a triple-bottom-line approach. This fundamental distinction underscores the unique methodological and theoretical challenges inherent in green innovation research.

The evolution of green innovation research has undergone significant transformations driven by three interrelated forces. First, regulatory frameworks like the Paris Agreement (2015) and the EU Green Deal set hard compliance thresholds. Companies had no choice but to put green criteria into their innovation portfolios (Porter & Linde, 1995). This sparked a ton of research into policy design and the Porter Hypothesis across manufacturing and services. Second, market demands shifted hard. Consumers, investors, and supply chain partners started prioritizing sustainability credentials, turning green practices into a real competitive advantage (Dangelico & Pontrandolfo, 2010). Suddenly, everyone was researching green consumer behavior and sustainable supply chains. Third, the field started pulling insights from operations management, environmental economics, industrial ecology, policy, and finance to tackle these massive sustainability problems (Adams et al., 2016). This mashup gave us cool new tools like life-cycle assessments, circular economy modeling, and green finance instruments.

These three forces have collectively reshaped the boundaries of green innovation research. Because the field is moving so fast, we really need a systematic bibliometric assessment just to map out where everything stands right now. Over time, the focus has expanded to include various factors influencing green innovation, such as technological capabilities and organizational characteristics (Wang & Yang, 2021). Corporate Environmental Responsibility (CER) has emerged as a strategic imperative for manufacturing and service operations alike. Rather than viewing environmental compliance as a cost burden, leading organizations now recognize CER as a catalyst for operational innovation and competitive differentiation (Wang et al., 2021). In sectors with high pollution or green demand, firms are more likely to innovate under environmental regulations, indicating that industry characteristics play a crucial role.

Despite the multidimensional nature of green innovation encompassing technological novelty, environmental performance, and social value creation, existing bibliometric analyses have predominantly examined isolated dimensions or narrow conceptualizations of the field. For instance, prior studies have focused exclusively on eco-innovation metrics, technological green patents (Wurlod & Noailly, 2018), or regional policy impacts (Ghisetti et al., 2015), without integrating these dimensions into a unified analytical framework. This fragmentation limits our understanding of how green innovation research has evolved holistically across its constituent domains. Consequently, a comprehensive bibliometric analysis that simultaneously captures technological, environmental, and social dimensions of green innovation remains conspicuously absent from the literature.

Now, all this fragmentation across disciplines, countries, and methods poses both a challenge and an opportunity. It reflects intellectual diversity and rapid expansion. But it also risks creating isolated knowledge silos, which honestly hinders us from building a cumulative theory. That's exactly why bibliometric analysis is uniquely suited here. It lets us systematically map citation networks, co-authorship structures, and thematic clusters across disconnected research streams (Zupic & Čater, 2015).

We should be clear about one thing, though. Finding thematic fragmentation through mapping does not mean the field is saturated; far from it. It actually reveals a maturing discipline with established core themes alongside emerging frontiers. Fragmentation just means specialized sub-communities are forming to tackle distinct aspects of green innovation. True saturation would look like declining publication rates, repetitive research questions, and dropping citation impacts. Our analysis shows the exact opposite pattern. We are seeing healthy diversification, which completely validates bibliometric analysis as the right, timely choice.

Statement of the Problem

Green innovation is particularly relevant to the attainment of specific Sustainable Development Goals (SDGs), notably SDG 9 (Industry, Innovation, and Infrastructure) and SDG 13 (Climate Action). By fostering resource-efficient technologies, sustainable industrial processes, and low-carbon operational systems, green innovation directly contributes to building resilient infrastructure, promoting inclusive industrialization, and combating climate change. However, the geographic distribution of green innovation research remains highly skewed toward developed economies, leaving significant gaps in our understanding of how developing and emerging economies can leverage green innovation for sustainable industrialization and climate resilience. This geographic imbalance not only limits the generalizability of existing findings but also impedes the transfer of green innovation knowledge to contexts where it is most urgently needed.

Because green innovation covers so many parts, and because past bibliometric studies have been so fragmented, we really need a comprehensive update. Plus, the field has been evolving incredibly fast since 2010. A fresh look is completely necessary right now. We are tackling these gaps head-on by analyzing 3,931 publications from the Scopus database. To do that, we're using performance analysis, co-citation mapping, co-word analysis, and temporal keyword evolution to trace how the intellectual structure and emerging trends have shifted over time. By pulling all these techniques into a single, unified framework and using grounded criteria to check the field's actual maturity, we can offer a much clearer picture of what's happening than prior reviews did.

Research Questions

1. What are the most prominent themes, keywords, and intellectual structures in green innovation research, and how have they evolved over the past decade?
2. Which countries, institutions, authors, and journals have made the most significant contributions to the field, and what is their relative impact?
3. What are the emerging research fronts and hot topics in green innovation, and what do they reveal about the field's future direction?

MATERIALS AND METHODS

This section outlines the specific methodologies employed in our bibliometric analysis of green innovation research. Our approach encompasses data collection, bibliometric analysis techniques, the use of VOS viewer software, and data cleaning procedures.

Database Selection and Time Frame

Scopus, a leading bibliographic database that's widely recognized for covering a massive amount of peer-reviewed literature across different disciplines (Baas et al., 2020), was used as a data source. About 96.61% of the journals indexed in Scopus are also found in Web of Science, which indicates this data source is incredibly reliable (Singh et al., 2021). Furthermore, Scopus has a great built-in tool for exporting all that bibliographic data to run a thorough analysis and actually understand research trends and outputs (Raminta, 2021). The interface and performance of Scopus are designed to support users in efficiently navigating and utilizing the data for various research purposes.

We explicitly chose to focus on publications from 2010 to 2023. We wanted to capture the most recent, highly relevant developments in green innovation research. Looking at the past decade, we've seen massive global shifts in environmental policy and sustainability initiatives. A huge milestone was the Paris Agreement in 2015. Events like that completely shifted the trajectory of green innovation research by forcing everyone to rethink compliance (Rogelj et al., 2016). This exact timeframe also aligns with an absolute explosion in research output focused on environmental sustainability and innovation. By drawing the line here, we get a massive, sufficient volume of publications to run a truly meaningful bibliometric analysis.

Search Strategy and Keywords

When we were setting up our search strategy, we wanted to make sure we caught a massive, wide-ranging net of papers on green innovation. To do that without losing our minds, we used standard Boolean operators like AND and OR to keep the results relevant. We ran a very specific search string through the Scopus database: (TITLE-ABS-KEY ("green innovation") OR TITLE-ABS-KEY("eco-innovation") OR TITLE-ABS-"KEY ("sustainable innovation") OR TITLE-ABS-"KEY ("environmental innovation")) AND PUBYEAR > 2009 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE, "English")).

Inclusion and Exclusion Criteria

To make sure we kept the quality and relevance high, we applied some explicit inclusion and exclusion criteria. For inclusion, we only looked at peer-reviewed articles, conference papers, book chapters, and reviews published in English between 2010 and 2023. Naturally, these papers had to focus directly on green innovation, eco-innovation, or closely related concepts. On the flip side, we completely excluded non-peer-reviewed stuff like editorials, short notes, and news articles. We also dropped publications that were purely theoretical with zero empirical analysis, papers that only tangentially mentioned green innovation, and anything written in languages other than English.

The PRISMA diagram (Figure 1) traces five stages: identification (4,847 records), screening (412 duplicates removed; 504 excluded), eligibility (3,931 assessed), inclusion (3,931 retained), and analysis pipeline (four bibliometric techniques via VOSviewer).

Bibliometric Analysis Techniques

Our analysis employed both performance analysis and science mapping techniques to provide a comprehensive overview of the green innovation research landscape (Donthu et al., 2021). We used performance analysis to track the productivity and actual impact of the research. This included publication output and citation analysis. First, we looked at the total number of publications per year to spot productivity trends over time. You'll notice this specific metric is great for seeing exactly how the field grew and how global interest in green innovation shifted across our timeline (Ole & Wallin, 2015). After that, we ran the citation analysis to evaluate the real weight and influence of individual papers, institutions, and authors.

To really see how green innovation research is structured, we used science mapping techniques to build a visual guide. The two big heavy-hitters we relied on were co-citation analysis and co-word analysis. We used co-citation analysis to map out the foundational intellectual structure of the field. Basically, this technique flags pairs of papers that constantly get cited together by other people, which reveals hidden conceptual links between different papers and research streams (Small, 1973). It's great for spotting the intellectual roots.

We also paired it with co-word analysis. By tracking how often specific keywords appear together in the same paper, we can map the conceptual structure, pick out the main themes, and see exactly how the research trends are moving over time.

VOSviewer Software

To actually build these maps, we used VOSviewer (version 1.6.20). It's a software tool explicitly designed for creating, visualizing, and exploring these massive bibliometric networks (Waltman et al., 2010). It can map out author collaborations, citation networks, and keyword co-occurrences all in one place. It is a total game-changer for science mapping (Waltman et al., 2016). It effortlessly handles huge datasets and spits out clean maps based on all sorts of bibliometric indicators.

We adjusted a few specific parameter settings in VOSviewer to keep the maps accurate. First, we set minimum thresholds for keyword occurrences and citations so only the most significant items made the cut. For example, we only included keywords that popped up in at least 10% of the documents. We also used the fractional counting method to normalize the data. It corrects for the fact that different fields and time periods have completely different publishing and citation habits. For the final visuals, we used network visualization to show the overall structure of the field and density visualization to pinpoint the absolute hottest areas of research activity. We just stuck with the default VOSviewer parameter settings for both because they've already been optimized through a ton of testing (Eck & Waltman, 2014).

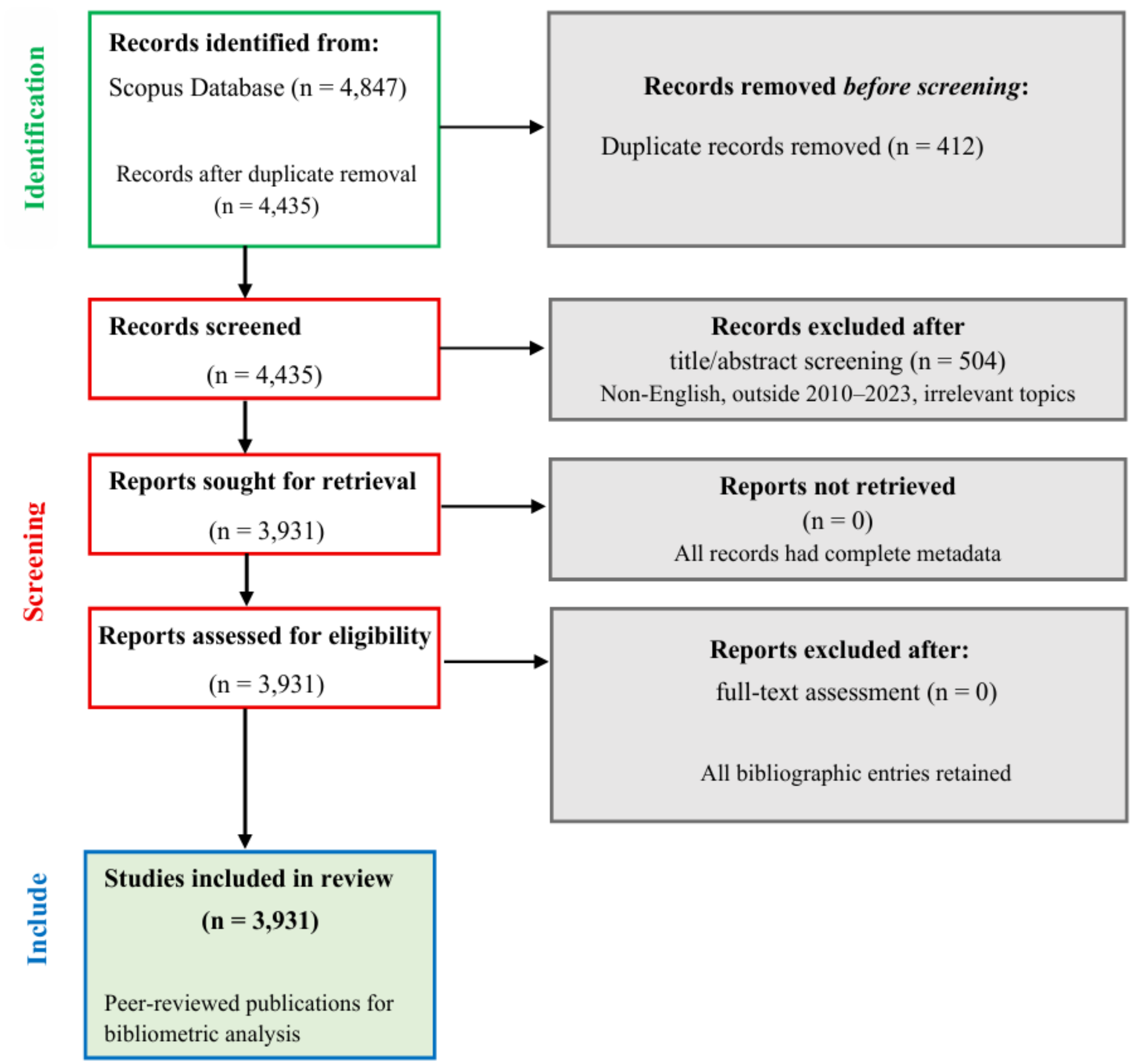

Figure 1. *PRISMA flow diagram illustrating the systematic data collection and screening*

Data Cleaning and Pre-processing Procedures

Before conducting the bibliometric analysis, data cleaning and pre-processing were essential steps to ensure the reliability and accuracy of the results. A comma-separated values (.csv) file format was used to extract the bibliometric data from the Scopus database. After downloading the data file, the acquired data underwent additional cleaning procedures to improve its accuracy and reliability. A thorough examination of each column, including year, source title, authors' names, and affiliations, was conducted to clean the dataset.

Variations in author names (due to spelling differences or use of initials) were standardized to ensure that all publications by a single author were correctly attributed. This was achieved using an algorithmic approach as well as manual verification. VOSviewer's thesaurus file feature was also used to address variations in author names and institutional affiliations. Keywords were standardized to account for variations in spelling, synonyms, and acronyms. This was achieved by merging synonyms and resolving acronyms to ensure consistency in our co-word analysis. When we first pulled the data, we found that terms like "eco-innovation" and "green innovation" were being treated as completely equivalent. To fix messy overlaps like that, we had to do some serious manual spot-checks on a random sample of publications just to verify that the bibliographic data was actually accurate.

We also had to hunt down and manually remove any invalid or missing entries scattered throughout the dataset. Once we finished that thorough cleaning and standardization process, we saved everything as a separate Microsoft Excel (.xls) file.

RESULTS AND DISCUSSION

Results

Publication Trends over Time

A total of 3,931 publications on green innovation were identified from 2010 to 2023. The annual output rose from 40 papers in 2010 to 1,213 papers in 2023, representing an increase of 2,932.5% over the 14-year period. Figure 2 charts this annual publication output. Year-over-year growth rates ranged from −7.8% (2011 to 2012) to 99.8% (2021 to 2022), with an average annual growth rate of 36.7%. A more pronounced increase commenced in 2015, with output rising from 97 publications to 264 by 2019. Logarithmic transformation of the data revealed a strong linear relationship (R^2 = 0.9464), indicating an exponential growth pattern. The number of publications nearly tripled between 2020 (343 publications) and 2023 (1,213 publications).

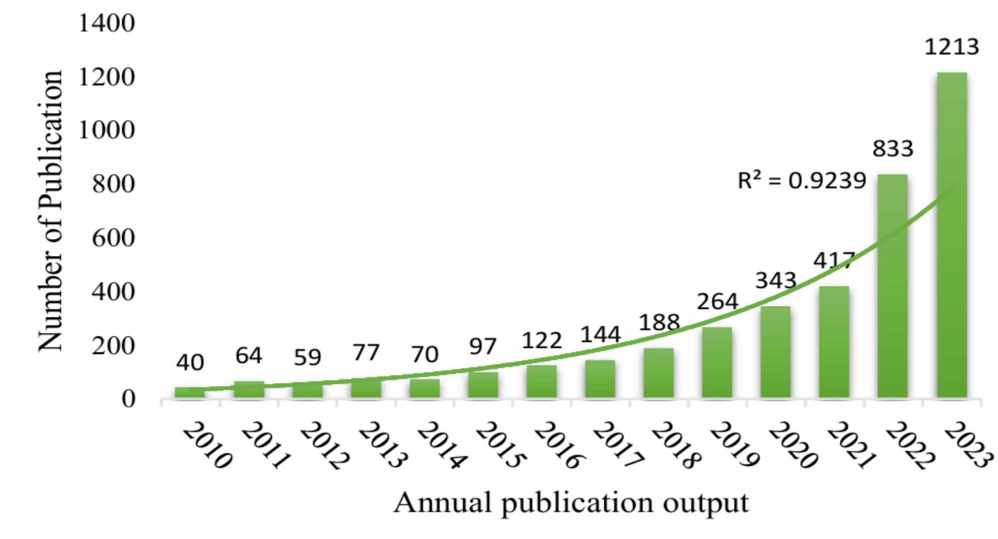

Figure 2. *Annual Publication Output on Green Innovation (2010-2023)*

Top Contributing Countries, Institutions, and Authors

Contributions on green innovation came from over 100 countries. Table 1 presents the top 10 countries by number of publications and total citations. China accounted for the largest share of publications among the top 10, with 1,866 papers and 66,331 total citations. The output exhibited a tiered structure: Tier 1 (>1,000 publications)—China; Tier 2 (200–400 publications)—United Kingdom, Spain, Italy, United States, Pakistan; Tier 3 (<200 publications)—Malaysia, Germany, Taiwan, France.

Table 1

Top 10 Contributing Countries to Green Innovation Research

Rank	Country	Number of Publications	Total Citations
1	China	1866	66331
2	United Kingdom	316	17513
3	Spain	253	14945
4	Italy	233	15856
5	United States	218	12566
6	Pakistan	208	11749
7	Malaysia	153	6241
8	Germany	144	10398
9	Taiwan	139	10027
10	France	138	8916

Figure 3 presents the Citations per Publication (CPP) and Relative Citation Impact (RCI) for each country. China recorded a below-average RCI of 0.92. Germany, Taiwan, and Italy exhibited RCI values exceeding 1.75. The United Kingdom, Spain, and the United States showed a balance between productivity and impact.

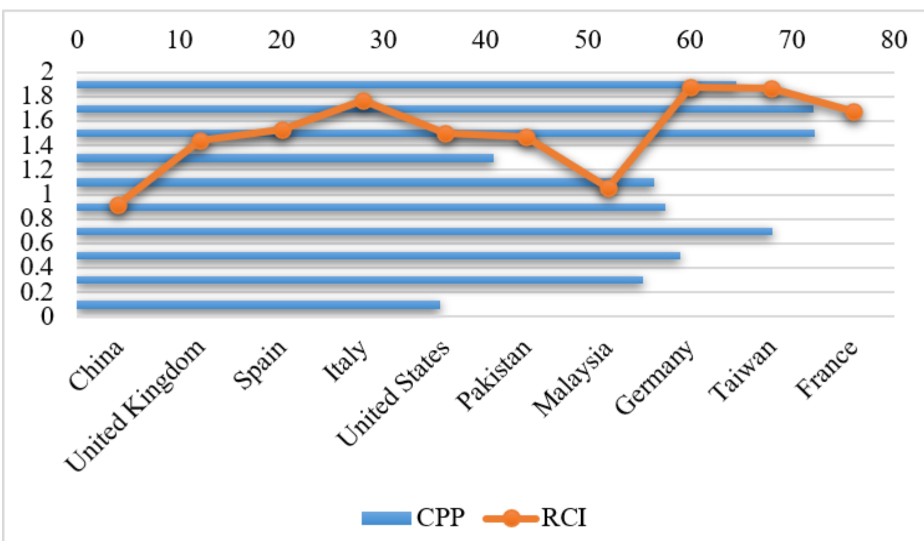

Figure 3. *Citation Metrics for Top 10 Countries in Green Innovation Research*

Table 2 lists the top 10 contributing institutions. Nine of the top 10 institutions are located in China. Jiangsu University was the most prolific (54 publications), followed by Beijing Institute of Technology and Xi'an Jiaotong University (45 each). Ilma University (Pakistan) ranked sixth with 34 publications. The Institutional Concentration Index (ICI), calculated using the Herfindahl-Hirschman Index (HHI) approach as ICI = $\Sigma (si^2) * 10000$, was 1,289 for the top 10 institutions.

Table 2

Top 10 Contributing Institutions to Green Innovation Research

Rank	Institution	Country	Number of Publications
1	Jiangsu University	China	54
2	Beijing Institute of Technology	China	45
3	Xi'an Jiaotong University	China	45
4	Harbin Engineering University	China	38
5	Zhejiang Sci-Tech University	China	37
6	Ilma University	Pakistan	34
7	North-western Polytechnical University	China	29
8	Central South University	China	27
9	Dalian University of Technology	China	21
10	Jilin University	China	21

Table 3 lists the top 10 most productive authors. Z. Liao (Zhejiang Sci-Tech University, China) was the most prolific author with 36 publications. The list includes researchers affiliated with institutions in Asia and Europe.

Most Influential Journals and Articles

Table 4 shows the top 10 journals by number of publications and impact factor.

Table 3

Top 10 Contributing Authors in Green Innovation Research

Rank	Author	Current Affiliation	Publications
1	Liao, Z.	Zhejiang Sci-Tech University, China	36
2	Chang, C.	Shih Chien University, Taiwan	23
3	Mazzanti, M.	University of Ferrara, Italy	18
4	Razzaq, A.	Dalian University of Technology, China	15
5	Yin, S.	Hebei Agricultural University, China	15
6	Irfan, M.	Beijing Institute of Technology, China, and ILMA University, Pakistan	14
7	Johl, S.	Universiti Teknologi PETRONAS, Malaysia	12
8	Scarpellini, S.	University of Zaragoza, Spain	12
9	Feng, G.	Xi'an Jiaotong University, China	10
10	Horbach, J.	University of Applied Sciences Augsburg, Germany	10

Table 4

Top 10 Most Influential Journals in Green Innovation Research

Rank	Journal Title	Publications	Impact Factor
1	Sustainability (Switzerland)	470	3.3
2	Journal of Cleaner Production	316	9.7
3	Environmental Science and Pollution Research	185	5.8
4	Business Strategy and the Environment	155	12.5
5	Technological Forecasting and Social Change	87	12.9
6	International Journal of Environmental Research and Public Health	81	4.6
7	Frontiers in Environmental Science	80	3.3
8	Journal of Environmental Management	46	8.0
9	Corporate Social Responsibility and Environmental Management	45	8.3
10	Economic Research-Ekonomska Istrazivanja	43	6.41

Sustainability (Switzerland) published the highest number of articles (470), followed by *Journal of Cleaner Production* (316). Journals with the highest impact factors—*Technological Forecasting and Social Change* (12.9) and *Business Strategy and the Environment* (12.5)—did not lead in publication volume. A trade-off between volume and impact factor was observed: high-volume journals such as *Sustainability* and *Frontiers in Environmental Science* had moderate impact factors, whereas lower-volume journals achieved higher citation impact.

Most Influential Articles

Table 5 lists the top 10 most cited articles. Citation counts ranged from 664 to 1,491. The most cited article, by Boons and Lüdeke-Freund (2013), received 1,491 citations. The highly cited works addressed themes including sustainable business models, institutional pressures driving green innovation (Berrone et al., 2013), determinants of eco-innovations (Horbach et al., 2012), green transformational leadership and human resource management (Singh et al., 2020), R&D cooperation (Marchi, 2012), supplier greening and competitive advantage (Chiou et al., 2011), corporate environmental ethics (Chang, 2011), big data and green innovation (El-Kassar & Singh, 2019), and green R&D and carbon emissions (Lee & Min, 2015).

Table 5

Top 10 Most Cited Articles in Green Innovation Research (2010–2023)

Rank	Title	Authors	Year	Citations
1	Business models for sustainable innovation: State-of-the-art and steps towards a research agenda	Boons, F., Lüdeke-Freund, F.	2013	1491
2	Necessity as the mother of 'green' inventions: Institutional pressures and environmental innovations	Berrone, P., Fosfuri, A., Gelabert, L., Gomez-Mejia, L.R.	2013	1100
3	Determinants of eco-innovations by type of environmental impact - The role of regulatory push/pull, technology push, and market pull	Horbach, J., Rammer, C., Rennings, K.	2012	1025

Table 5 continues

4	Green innovation and environmental performance: The role of green transformational leadership and green human resource management	Singh, S.K., Giudice, M.D., Chierici, R., Graziano, D.	2020	983
5	Environmental innovation and R&D cooperation: Empirical evidence from Spanish manufacturing firms	Marchi, V.	2012	903
6	The influence of greening the suppliers and green innovation on environmental performance and competitive advantage in Taiwan	Chiou T.-Y., Chan H.K., Lettice F., Chung S.H.	2011	902
7	Sustainable innovation, business models, and economic performance: An overview	Boons, F., Montalvo, C., Quist, J., Wagner, M.	2013	748
8	The Influence of Corporate Environmental Ethics on Competitive Advantage: The Mediation Role of Green Innovation	Chang C.-H.	2011	704
9	Green innovation and organizational performance: The influence of big data and the moderating role of management commitment and HR practices	El-Kassar A.-N., Singh S.K.	2019	704
10	Green R&D for eco-innovation and its impact on carbon emissions and firm performance	Lee K.-H., Min B.	2015	664

Co-citation Analysis

Author Co-citation

The author's citation network (Figure 4) revealed three distinct clusters. Cluster 1 (red) comprised authors such as Rennings, Wagner, Jaffe, and Cohen, and was associated with eco-innovation and environmental policy. Cluster 2 (green) included Wang, Li, Chen, and Ren, focusing on management and technological aspects of green innovation. Cluster 3 (blue) featured Ahmad, Chien, and Mohsin, centered on sustainable business models and performance.

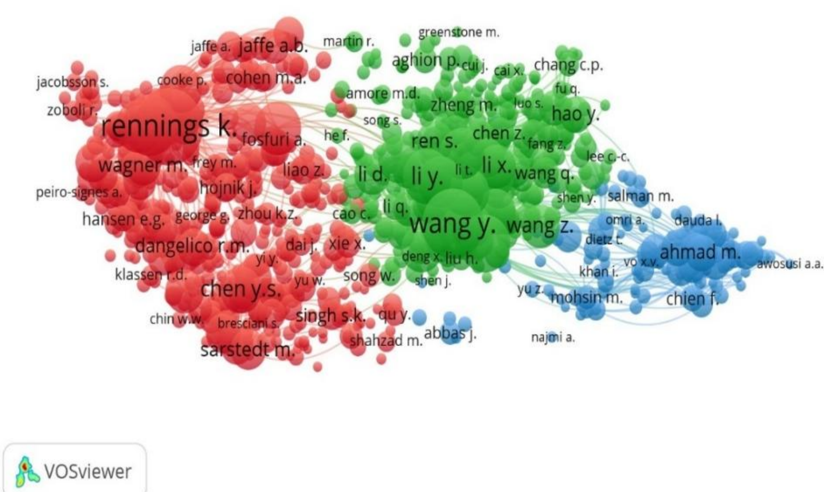

Figure 4. *Author co-citation network in green innovation research*

Journal Co-citation

The journal co-citation network (Figure 5) also contained three clusters. The red cluster was anchored by the Journal of Cleaner Production. The green cluster is centered on Renewable & Sustainable Energy Reviews and Energy Policy. The blue cluster had Resources, Conservation & Recycling as a central node. Technological Forecasting and Social Change and Research Policy occupied bridging positions between clusters.

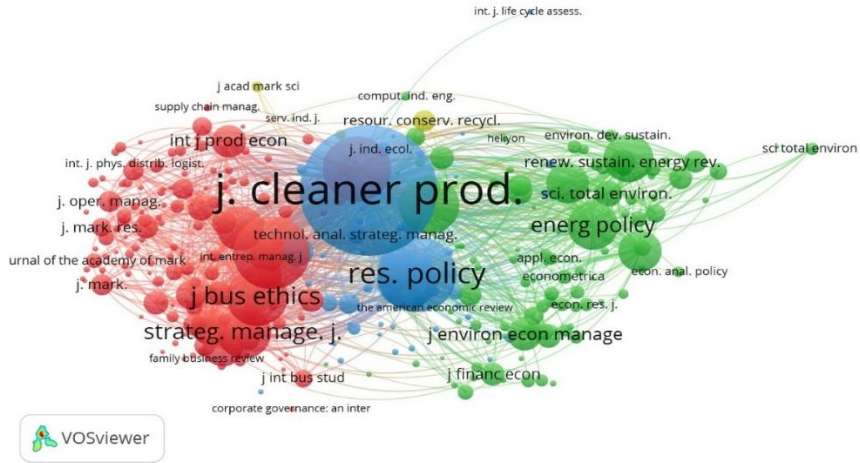

Figure 5. *Journal co-citation network in green innovation research*

Keyword Co-occurrence Analysis

Temporal Evolution of Keywords

Figure 6 displays the temporal overlay of keywords. Keywords appearing in blue-green tones, indicating earlier average publication years, included "green innovation," "eco-innovation," "innovation," "corporate social responsibility," "stakeholder," and "leadership." Keywords in yellow, representing more recent research, included "carbon emission," "renewable energy," "economic growth," "economic development," "green finance," "green credit policy," "spatiotemporal analysis," "panel data," and "heterogeneity." Emerging geographic terms included "India," "Pakistan," "Russian Federation," and "BRICS."

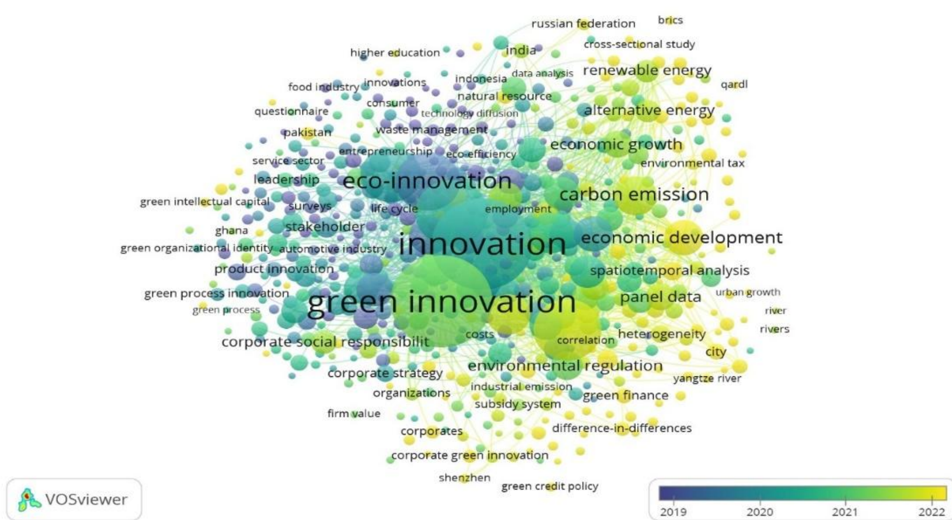

Figure 6. *Temporal evolution of keywords in green innovation research*

Thematic Clusters and their Interconnections

The network visualization of all keywords (Figure 7) identified five thematic clusters.

Red cluster (core concepts): "eco-innovation," "innovation," "corporate social responsibility," "stakeholder," "leadership," "product innovation," and "green process innovation."

Blue cluster (economic and environmental outcomes): "economic growth," "economic development," "carbon emissions," "renewable energy," "alternative energy," "India," and "BRICS."

Green cluster (corporate practices and regulatory frameworks): "corporate green innovation," "green credit policy," "corporate strategy," "environmental regulation," "green finance," and "subsidies."

Purple cluster (sectoral and regional applications): "higher education," "automotive," "service," "food industries," and "Pakistan."

Yellow cluster (research methods and data): "panel data," "spatiotemporal analysis," "heterogeneity," "correlation," "city," and "rivers."

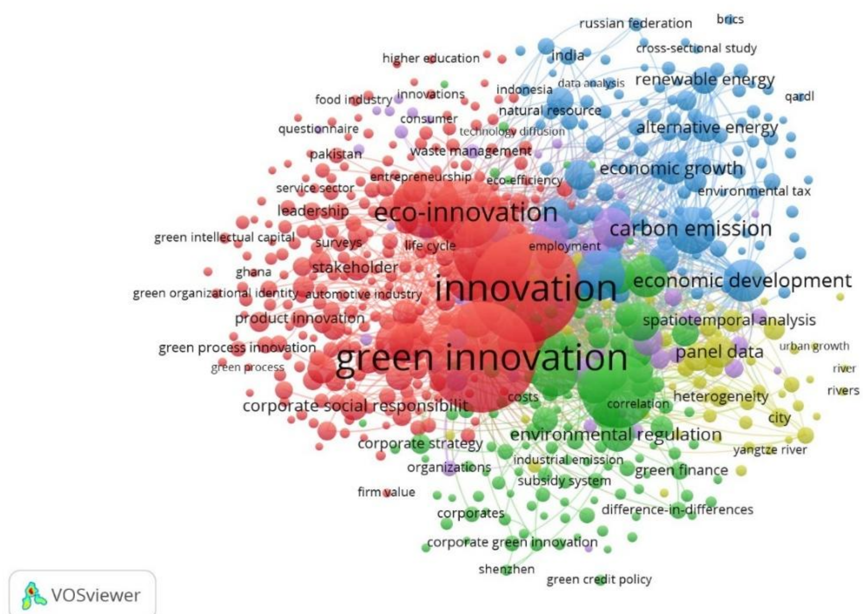

Figure 7. *Network visualization of all keywords in green innovation research*

Hot Topics and Emerging Research Fronts

Table 6 lists the top 10 keywords by occurrence and total link strength (TLS). "Green innovation" (occurrence 1,716; TLS 11,166) and "innovation" (1,681; TLS 15,454) were the most prevalent. Other high-frequency keywords included "sustainable development" (874), "eco-innovation" (688), "sustainability" (609), "environmental innovation" (446), "environmental regulation" (355), "environmental economics" (344), "green economy" (325), and "carbon emission" (313). Environmentally related terms featured prominently.

Table 6

Top 10 Hot Topics in Green Innovation Research

Keyword	Occurrences	TLS
Green Innovation	1716	11166
Innovation	1681	15454
Sustainable Development	874	7572

Table 6 continues

Eco-innovation	688	4354
Sustainability	609	4855
Environmental Innovation	446	1838
Environmental Regulation	355	1508
Environmental Economics	344	4130
Green Economy	325	3682
Carbon Emission	313	3570

Table 7 presents keywords with low occurrence (10–11), representing less-frequent topics. Among these, "Prevention and Control" (TLS 180), "Green Energy" (TLS 173), and "Energy Transitions" (TLS 154) recorded the highest TLS values. Other low-occurrence keywords included "Collaborative Innovation" (TLS 75), "Eco-Innovation Drivers" (TLS 47), "Emission Reduction" (TLS 93), "Environmental Patent" (TLS 115), "Green Organizational Culture" (TLS 50), "Green Technological Innovation" (TLS 107), "Regional Differences" (TLS 96), "Regulatory Pressure" (TLS 62), "Resource Efficiencies" (TLS 112), "Technology Diffusion" (TLS 107), "Urban Growth" (TLS 101), "Value Creation" (TLS 66), "Ecotourism" (TLS 70), "Environmental Uncertainty" (TLS 52), "Green Entrepreneurship" (TLS 51), "Green Process" (TLS 114), and "Industrial Ecology" (TLS 103).

Table 7

Emerging Research Fronts in Green Innovation

Keyword	Occurrences	TLS
Collaborative Innovation	10	75
Eco-Innovation Drivers	10	47
Emission Reduction	10	93
Environmental Patent	10	115
Green Energy	10	173
Green Organizational Culture	10	50
Green Technological Innovation	10	107
Prevention and Control	10	180
Regional Differences	10	96
Regulatory Pressure	10	62
Resource Efficiencies	10	112
Technology Diffusion	10	107
Urban Growth	10	101
Value Creation	10	66
Ecotourism	11	70
Energy Transitions	11	154
Environmental Uncertainty	11	52
Green Entrepreneurship	11	51
Green Process	11	114
Industrial Ecology	11	103

Discussion

The results reveal exponential growth in green innovation research and highlight the field's global yet concentrated nature, with clear patterns of productivity and impact across countries, institutions, authors, journals, and themes. These patterns invite several interpretations regarding the field's maturation and future directions.

The dramatic increase in publications, particularly the sharp acceleration after 2015, coincides with the adoption of the United Nations Sustainable Development Goals (SDGs). The SDGs provided a framework that aligned innovation efforts with sustainability objectives, thereby spurring research interest in green innovation (Schot & Steinmueller, 2018). The strong linear fit on a logarithmic scale ($R^2 = 0.9464$) confirms an exponential growth pattern consistent with the broader historical trend of scientific output expansion (Van Noorden, 2014). The near-tripling of publications between 2020 and 2023 marks a phase of maturation in which green innovation has become a central topic in academic and policy discourse.

China's overwhelming share of publications reflects its national policy emphasis on sustainability and substantial investments in research infrastructure (Zhou & Leydesdorff, 2006). However, China's below-average relative citation impact (RCI = 0.92) aligns with observations that the proportional growth in high-impact, internationally collaborative research requires continued development (Zhou et al., 2021). In contrast, Germany, Taiwan, and Italy achieve higher citation impacts (RCI > 1.75), underscoring the quality and international visibility of European and Taiwanese research in this domain (Horbach et al., 2012). The United Kingdom, Spain, and the United States display a balanced productivity–impact profile, reflecting their robust research infrastructures and sustained support for sustainability initiatives.

At the institutional and author levels, the moderate concentration (ICI = 1,289) and the prominence of specific Chinese and select European/Pakistani entities suggest a distributed yet hierarchically structured research ecosystem. The presence of authors like Liao, Z. (36 publications), alongside European contributors such as Mazzanti and Scarpellini, underscores both regional strengths and the global character of the field. Journal patterns similarly show a trade-off between volume (e.g., *sustainability)* and impact (e.g., *Technological forecasting and social change, business strategy and the environment),* indicating that different outlets serve complementary roles in knowledge dissemination.

Co-citation networks illuminate the intellectual structure: the red author cluster emphasizes policy and eco-innovation determinants, the green cluster managerial and technological adoption, and the blue cluster sustainable business models. Journal clusters reinforce foci on cleaner production, energy transitions, and circular economy principles. These structures highlight how green innovation research integrates environmental policy, management practice, and technological forecasting.

Keyword analyses reveal a clear evolution from foundational organizational and ethical themes toward macroeconomic outcomes, energy transitions, green finance, and methodological sophistication. The shift toward emerging economies (BRICS nations) and advanced techniques (panel data, heterogeneity) signals increasing policy relevance and analytical rigor. Hot topics center on core concepts like "green innovation" and "sustainable development," while low-frequency terms (e.g., green energy, energy transitions, collaborative innovation, and regional differences) identify promising frontiers. Addressing these gaps—particularly proactive strategies, sectoral applications, and contextual variations in developing regions—could substantially advance both theory and practice.

Overall, the findings portray green innovation as a dynamic, interdisciplinary field with strong momentum, yet they also imply the need for enhanced international collaboration, quality focus in high-volume contexts, and deeper exploration of underrepresented themes to fully realize its potential for sustainability transitions. Limitations include the Scopus-based dataset scope and the bibliometric focus, which prioritizes quantitative patterns over qualitative depth. Future work should integrate mixed methods and expand to other databases for a more complete view.

CONCLUSIONS

This study advances the understanding of green innovation research by providing the most comprehensive bibliometric analysis to date, encompassing 3,931 publications from 2010 to 2023. Our findings reveal a field that has transitioned from fragmented, conceptually nascent research to a mature, multidisciplinary domain characterized by specialized sub-communities, interdisciplinary integration, and applied orientation. The annual output surged from 40 papers in 2010 to 1,213 in 2023, with a pronounced acceleration after 2015 that reflects the galvanizing effect of global policy frameworks such as the Sustainable Development Goals. China has emerged as the predominant producer of green innovation scholarship, dominating publication volume, institutional presence, and author productivity. However, the citation impact of Chinese research, as measured by relative citation impact, remains below the global average, whereas several European countries and Taiwan achieve disproportionately strong influence despite smaller volumes of output.

The intellectual structure of the field, revealed through co-citation networks, rests on three pillars: environmental policy and regulation, management and technological innovation, and sustainable business models. Journal co-citation patterns further underscore the centrality of cleaner production and energy transition research, with high-impact journals bridging technological, policy, and business perspectives. Thematic evolution traced through keyword analysis charts a clear shift from foundational organizational concepts such as corporate social responsibility and leadership toward macro-economic concerns, including carbon emission reduction, renewable energy, and green finance. Concurrently, the field has embraced more sophisticated quantitative methodologies, integrating spatiotemporal analysis and panel data techniques.

A notable geographic pivot toward emerging economies—especially the BRICS nations—signals a broadening of the research context, as scholars increasingly investigate how green innovation is adopted and adapted in regions critical to global sustainability. Despite considerable progress, the analysis identified a series of underexplored research fronts, including collaborative innovation, eco-innovation drivers, green organizational culture, regional differences, and green entrepreneurship, which collectively delineate the next frontier for scholarly inquiry.

Recommendations

Future research should prioritize the identified emerging fronts, including green energy integration, energy transitions, collaborative innovation, regional differences, green organizational culture, and technology diffusion, particularly through comparative studies across developed and developing economies (e.g., BRICS nations). Greater emphasis on mixed-methods approaches, combining bibliometric insights with qualitative case studies or longitudinal econometric analyses (leveraging panel data and heterogeneity testing), would enrich understanding of causal mechanisms and contextual nuances.

Policymakers and institutions are encouraged to strengthen green finance mechanisms, such as green credit policies and subsidies, while fostering international collaborations to elevate research quality and visibility in high-volume contexts like China. Academic institutions should invest in interdisciplinary programs linking green innovation with sectoral applications (e.g., automotive, higher education, waste management) and proactive strategies for emission reduction, prevention, and control. Practitioners, especially in emerging markets, can benefit from adopting insights on sustainable business models, green transformational leadership, and big data integration to enhance organizational performance and competitive advantage.

To address current limitations, subsequent studies should expand datasets beyond Scopus, incorporate more recent publications, and examine qualitative dimensions of influence. Enhanced focus on underrepresented themes such as green entrepreneurship, environmental uncertainty, and industrial ecology will help bridge research gaps and support more effective sustainability transitions globally.

CRediT Authorship Contribution Statement

Geda Jebel Ababulgu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing - Original Draft; **Zerihun Ayenew Birbirsa**: Resources, Supervision, Validation, Writing - Review & Editing; **Misganu Getahun Wodajo**: Resources, Software, Supervision, Validation;

Declaration of Competing Interest

The authors affirm that they possess no acknowledged financial conflicts of interest or personal affiliations that may have seemingly impacted the research presented in this manuscript.

Ethical Approval

This study involves no primary data collection, human participants, animal subjects, or sensitive personal information. However, the authors conducted the study in full compliance with ethical standards for academic research.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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