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A Bibliometric Review of Green Innovation Research in Business and Economics: Intellectual Structure, Thematic Evolution, and Research Fronts

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Abstract: *This study examines the intellectual structure and thematic evolution of the green innovation literature through bibliometric methods, with a particular focus on knowledge production dynamics. Drawing on publications retrieved from the Web of Science database, an integrated set of analyses was employed, including thematic mapping, multiple correspondence analysis, thematic evolution analysis, keyword co-occurrence networks, as well as co-authorship, co-citation, and bibliographic coupling analyses. Taken together, the findings suggest that green innovation research has expanded not only in quantitative terms but also in conceptual scope, evolving into a thematically dynamic and globally asymmetric field. The literature appears to have shifted from early environmentally oriented perspectives toward a more outcome-driven framework that increasingly integrates technology, firm performance, and sustainable value creation. One notable observation is that the field is shaped by both highly influential foundational studies and network-based collective knowledge production processes. From a methodological perspective, the results indicate that the combined use of multiple bibliometric techniques is effective in capturing both the structural configuration and the dynamic development of the research field. While the analysis provides a comprehensive overview of the literature, it does not aim to exhaust all possible conceptual dimensions of green innovation research. Overall, the findings are expected to inform future theoretical and empirical studies and to contribute to a more holistic understanding of green innovation research.*

Keywords: Green Innovation, Sustainability, Bibliometric Analysis, Knowledge Mapping, Research Trends

JEL: Q55, O31, O32, C88

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1. Introduction

Growing environmental degradation and climate change at the global level have placed green innovation at the center of both policy agendas and academic research within the framework of sustainable development goals (Demirel, 2025; Matos, 2022). Given that approximately 70% of global greenhouse gas emissions originate from energy, manufacturing, and industrial activities, environmentally friendly innovations in production processes have gained strategic importance (IPCC, 2023). Alongside international environmental regulations such as the Kyoto Protocol and the Paris Climate Agreement, the rising environmental awareness of consumers has compelled firms to reassess traditional production and management practices and to adopt environmentally oriented innovations (Kammerer, 2009; Porter & van der Linde, 1995; Triguero et al., 2013; UNFCCC, 1997; UNFCCC, 2015). In this context, green innovation

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represents not merely a requirement of environmental responsibility for firms, but has also emerged as a strategic instrument for achieving competitive advantage, enhancing corporate reputation, and sustaining long-term performance (Chen, 2008; Dangelico & Pujari, 2010; Porter & van der Linde, 1995). Green innovation is commonly defined as innovations that are new to an organization and contribute to the reduction of environmental impacts through products, processes, or managerial practices (Chen et al., 2006; Rennings, 2000). Although closely related concepts such as eco-innovation and sustainable innovation are widely used, this study focuses on green innovation due to its relatively coherent usage within business and economics research.

Early studies in the green innovation literature primarily focused on the relationship between environmental regulations and innovation, particularly examining how regulatory frameworks could stimulate firms' innovative behavior (Jaffe & Palmer, 1997; Porter & van der Linde, 1995; Rennings, 2000). These studies laid the theoretical foundation of the field by arguing that environmental policies should not be viewed solely as cost burdens, but rather as potential catalysts for technological renewal and competitive advantage. In subsequent periods, research increasingly concentrated on firm-level determinants and performance outcomes of green innovation, thereby introducing a more organizational and strategic perspective to the literature (Brunnermeier & Cohen, 2003; Chen et al., 2006; Horbach, 2008).

The growing scholarly interest in green innovation is clearly reflected in the academic literature. Particularly since the second half of the 2010s, a marked acceleration has been observed in the number of publications in this field. Green innovation has evolved into a rapidly expanding research domain situated at the intersection of environmental economics, innovation management, strategic management, and sustainability studies (Odabaş, 2024). Bibliometric reviews covering the period from 2000 to 2023 consistently indicate a steady quantitative growth in green innovation research and suggest that the field has entered a phase of maturation (e.g., Albort-Morant et al., 2017; Rupasinghe et al., 2024; Yin et al., 2018; Zhang et al., 2024). Nevertheless, this expansion does not present an equally clear picture in terms of the structural coherence of the literature (Rupasinghe et al., 2024).

Despite its rapid growth, the green innovation literature exhibits a fragmented conceptual and methodological structure. The interchangeable use of concepts such as "green innovation," "eco-innovation," and "sustainable innovation" across many studies suggests that a shared conceptual framework across theoretical perspectives and disciplinary boundaries has yet to be fully established (Adams et al., 2016; Boons & Lüdeke-Freund, 2013; Carrillo-Hermosilla et al., 2010; Hojnik & Ruzzier, 2016; Schiederig et al., 2012). This conceptual diversity and terminological differentiation have long been debated within the literature. The use of different labels—such as eco-innovation, sustainable innovation, or environmental innovation—by various disciplines to describe similar phenomena complicates the clarification of conceptual boundaries and contributes to a fragmented research landscape (Dangelico & Pujari, 2010; Rennings, 2000; Schiederig et al., 2012). Similarly, empirical findings regarding the determinants, outcomes, and application domains of green innovation are often dispersed across studies focusing on specific subthemes or contextual settings (Cisneros Chavira et al., 2023). This fragmentation indicates that systematic studies offering a comprehensive overview of the intellectual structure, thematic evolution, and dominant research trajectories of green innovation remain limited.

Bibliometric analysis provides a powerful methodological tool for examining such fragmented and multidisciplinary bodies of literature. By employing quantitative techniques to analyze publication relationships, citation networks, and thematic concentrations, bibliometric methods enable the visualization of a research field's intellectual and social structure (Zupic & Čater, 2015). Through this approach, dominant themes, influential studies, collaboration patterns, and temporal transformations within the literature can be systematically mapped (Donthu et al., 2021; Ramos-Rodríguez & Ruíz-Navarro, 2004). However, existing bibliometric studies on green innovation, while valuable in identifying major trends and thematic clusters, predominantly rely on single bibliometric techniques and tend to overlook the simultaneous examination of conceptual evolution, intellectual foundations, and network-based knowledge production dynamics (Akbari et al., 2022; Albort-Morant et al., 2017; Zhang et al., 2024). As a result, integrative analyses that combine structural, temporal, and relational perspectives remain limited.

In addition, the positioning of green innovation within the business and economics literature, particularly in relation to performance and competitiveness outcomes, has not been sufficiently highlighted. To address these gaps, the present study adopts a multidimensional bibliometric design that integrates thematic mapping, temporal evolution, and citation based network analyses. This approach enables a more comprehensive understanding of the field's structural configuration and its consolidation over time. It also clarifies the emerging research front and makes the performance and competitiveness axis more visible within the literature.

Against this backdrop, the present study aims to systematically map the green innovation literature through a multidimensional bibliometric approach. To this end, thematic mapping, multiple correspondence analysis (MCA), thematic evolution analysis, co-citation analysis, and bibliographic coupling are employed in a complementary manner to examine the conceptual structure of the field, its evolution over time, and its dominant research orientations within an integrated framework. Compared to prior bibliometric research, this study distinguishes itself by covering a broader temporal span, applying multiple analytical techniques simultaneously, and explicitly linking green innovation to performance, competitiveness, and organizational outcomes, thereby strengthening its relevance to the business, management, and economics literature. The findings are expected to deepen ongoing theoretical discussions and to provide a guiding framework for future research in the field.

The remainder of the study is structured as follows. The second section outlines the research methodology, describing the data collection process and the bibliometric analysis techniques employed. The third section presents the findings through thematic mapping, conceptual structure analysis, and network-based bibliometric analyses. In the fourth section, the findings are discussed in light of the relevant literature, and the theoretical and empirical contributions of the study are evaluated. The final section summarizes the main conclusions, addresses the limitations of the study, and offers suggestions for future research.

2. Method

In line with the research objective, this study employs a multidimensional set of bibliometric methods. In this study, a bibliometric analysis approach is adopted to examine the development, thematic orientations, and research trends of the scientific literature on green innovation. Bibliometric analysis is a well-established method that systematically investigates the quantitative and relational characteristics of academic publications within a given research field, thereby revealing its intellectual structure, developmental dynamics, and dominant research clusters (Donthu et al., 2021; Zupic & Čater, 2015). Accordingly, rather than providing descriptive accounts of individual publications, the study focuses on relational patterns among publications to offer a holistic analysis of the conceptual and structural configuration of the green innovation literature.

During the literature retrieval process, the terms "green innovation," "eco-innovation," and "sustainable innovation" were initially examined. However, it was observed that the concepts of "eco-innovation" and "sustainable innovation" are employed within different theoretical frameworks and partially overlapping yet distinct research contexts in the literature (Boons & Lüdeke-Freund, 2013; de Jesus & Mendonça, 2018; Schiederig et al., 2012). For this reason, the search query was restricted to publications in which the term "green innovation" appears in the title, abstract, or author keywords.

Data collection was conducted using the Web of Science Core Collection database. Web of Science is widely recognized as a reliable data source in bibliometric research within the social sciences due to its selective indexing policy, interdisciplinary coverage, and quality-based filtering criteria (Falagas et al., 2008; Mongeon & Paul-Hus, 2016; Zupic & Čater, 2015). The retrieved data were processed to enable both descriptive statistical analyses and network-based analyses (Donthu et al., 2021; Zupic & Čater, 2015).

In the analysis phase, VOSviewer software was employed to construct visual network maps and identify clustering structures within the literature (Waltman et al., 2010). VOSviewer facilitates the visualization of author collaborations, citation relationships, and linkages among key concepts, thereby enabling the analysis of the intellectual, social, and conceptual structure of a research field (Donthu et al.,

2021; van Eck & Waltman, 2010; van Eck & Waltman, 2014). Threshold values used in the bibliometric network analyses were determined in line with widely accepted practices in the literature to prevent excessive network fragmentation and to ensure analytically interpretable clusters (Donthu et al., 2021; Zupic & Čater, 2015). These visual analyses were complemented by bibliometrix-based analyses conducted using the R programming language. Through the bibliometrix package, thematic mapping, MCA, thematic evolution analysis, bibliographic coupling, and co-citation analyses were performed. The combined use of these two software tools enables a comprehensive evaluation of bibliometric findings from both visual and statistical perspectives (Aria & Cuccurullo, 2017; Moral-Muñoz et al., 2020).

The bibliometric dataset of the study was constructed based on a search conducted in the Web of Science Core Collection database on December 10, 2025. Using the keyword "green innovation," a total of 7,511 publications covering the period from 1998 to 2025 were retrieved. The starting year of 1998 was selected because it corresponds to the period in which the term "green innovation" began to be used consistently within the Web of Science Core Collection. Of the retrieved publications, 7,070 were peer-reviewed journal articles, and only this document type was included in the analysis. In terms of disciplinary scope, 2,480 publications were classified under the subject categories of "Management," "Economics," and "Business." Among these, 2,469 articles were published in journals indexed in SSCI, ESCI, and SCI-EXPANDED, and only publications within these indices were included in the final dataset. The resulting dataset was analyzed at the levels of authors, citations, journals, countries, institutions, and keywords in order to reveal the structural and thematic characteristics of the green innovation literature.

3. Results

In this study, rather than ranking prominent authors or individual publications in the green innovation literature, the primary objective is to reveal the field's intellectual structure, thematic orientations, and prevailing research trends. Accordingly, the findings are presented primarily through bibliometric network structures and relational patterns, rather than descriptive lists. The findings section adopts a holistic perspective by examining the conceptual configuration of the literature, interactions among key actors, and the intellectual foundations of the field through multiple bibliometric techniques.

3.1. Conceptual and Thematic Framework

3.1.1. Thematic Map Analysis (R-Based)

The thematic mapping analysis (see Figure 1) reveals that the key concepts in the green innovation literature are structured into four main thematic categories based on their levels of centrality and density. Accordingly, *basic themes, motor themes, niche themes, and emerging or declining themes* are identified within the literature (Aria & Cuccurullo, 2017; Callon et al., 1991; Cobo et al., 2011). Figure 1a presents the foundational thematic structure of the green innovation literature. Concepts such as *performance*, *impact*, and *management* emerge as basic themes, characterized by high centrality and relatively moderate density. This positioning indicates that these concepts play an integrative role by linking multiple research streams and shaping the overall conceptual architecture of the field. In contrast, themes such as *research and development*, *knowledge*, and *models*exhibit higher density but lower centrality, suggesting internally coherent yet more narrowly focused research trajectories (Callon et al., 1991; Xia & Zhong, 2021).

Figure 1a. Thematic Mapping of Green Innovation Research-1 (Centrality–Density Diagram)

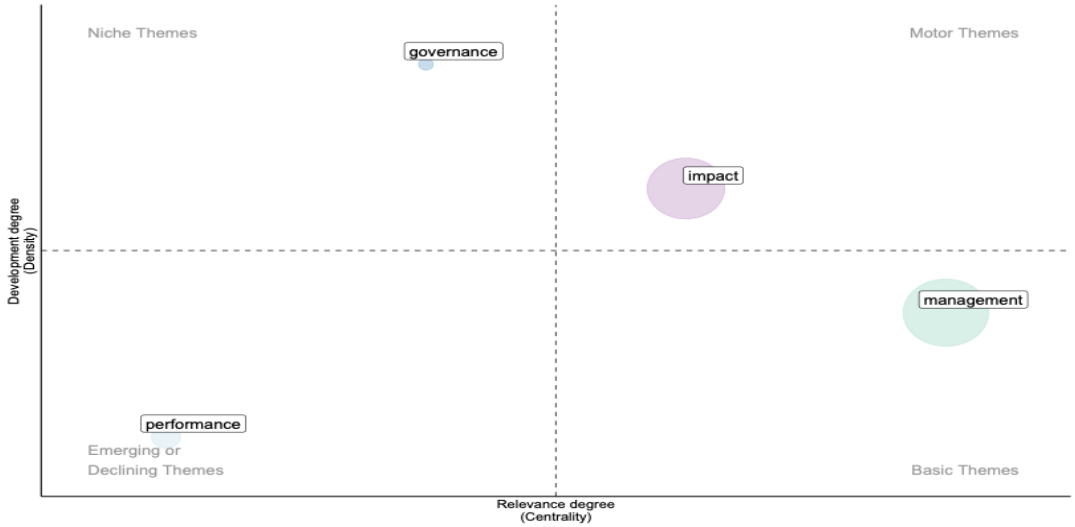


Figure 1b illustrates a thematic configuration centered on governance- and policy-related issues. While *management* and *impact* remain centrally positioned, *governance* appears as a niche theme, displaying high density but limited centrality. Governance-focused studies form a mature yet weakly integrated stream within the broader literature. The peripheral positioning of *performance* within this configuration suggests a temporary thematic shift toward institutional and regulatory perspectives (Cobo et al., 2011; Johri et al., 2024; Rodríguez-López et al., 2020).

Figure 1b. Thematic Mapping of Green Innovation Research-2 (Centrality–Density Diagram)

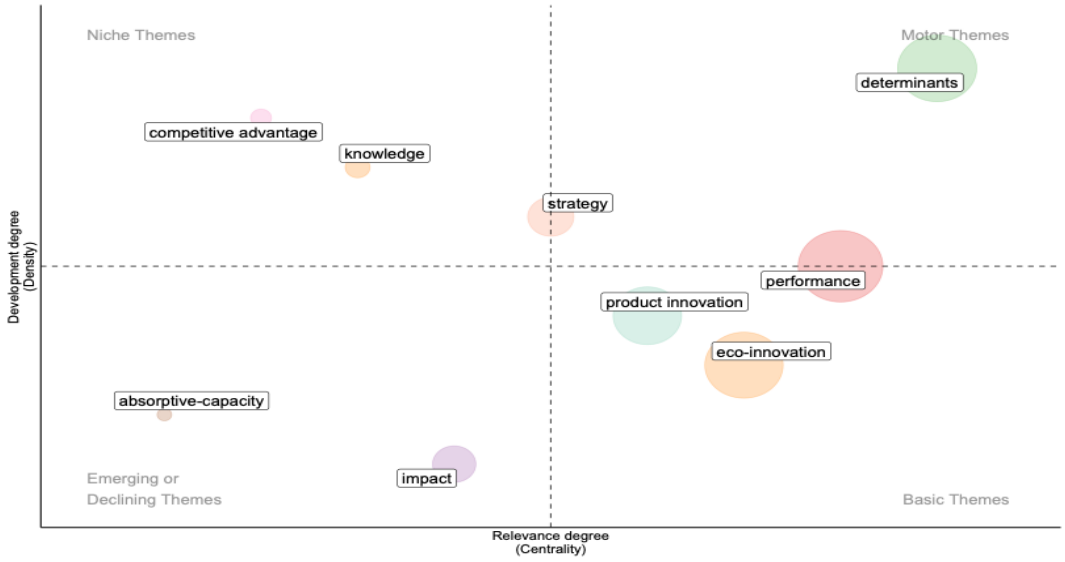


Figure 1c reveals a highly specialized thematic configuration dominated by *culture* as a niche theme. The combination of high density and low centrality indicates a well-developed but weakly connected body of research (Cobo et al., 2011). Cultural perspectives appear internally coherent but remain peripheral to dominant performance and strategy debates.

Figure 1c. Thematic Mapping of Green Innovation Research-3 (Centrality–Density Diagram)

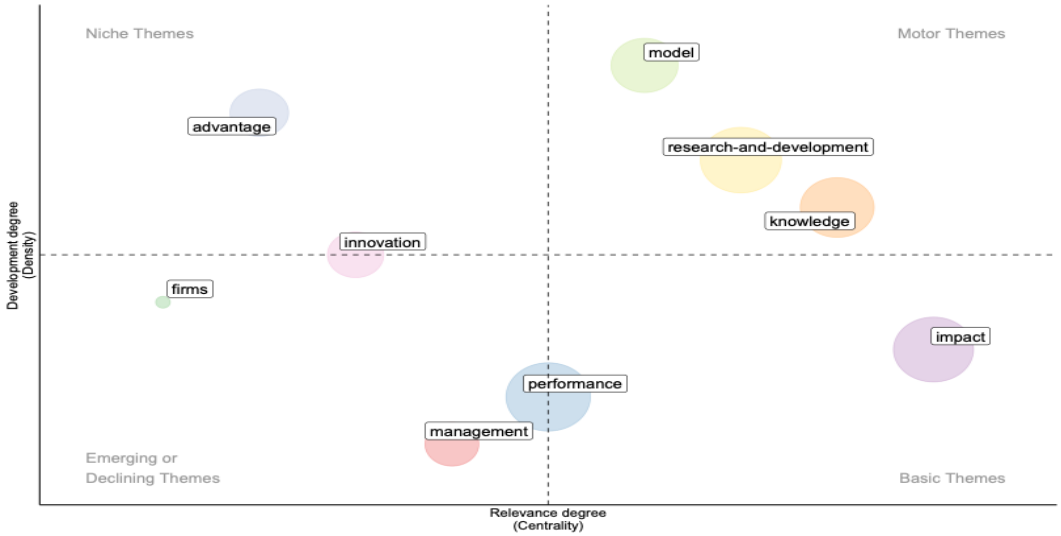
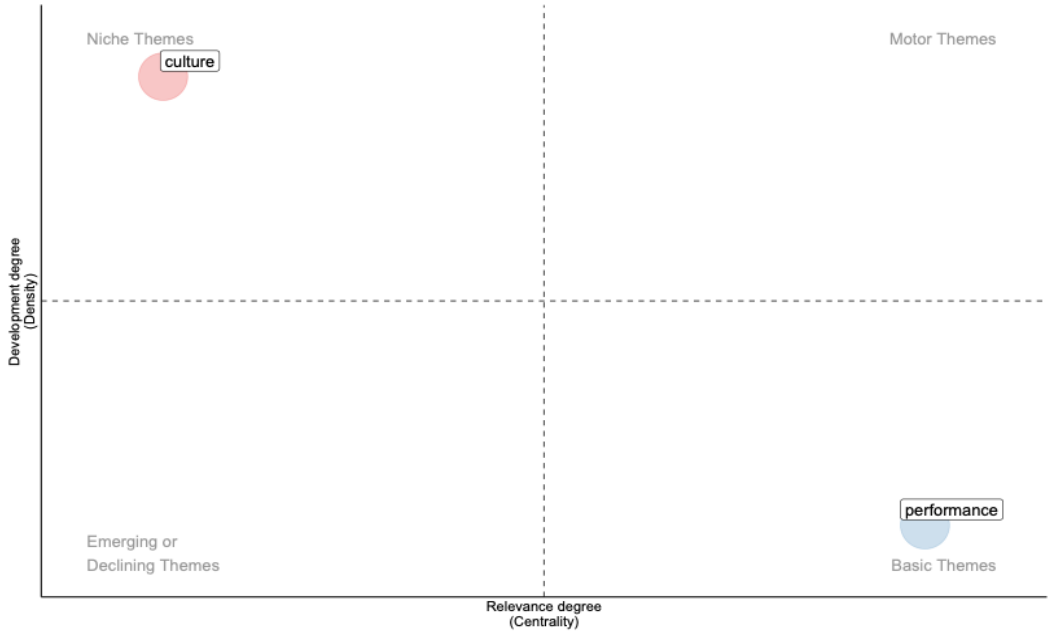


Figure 1d depicts a strategy-driven thematic architecture in which *eco-innovation*, *product innovation*, *strategy*, and *performance* emerge as ***motor themes***, combining high centrality with high density. This configuration reflects a mature and influential research core that actively drives the development of the green innovation field. By contrast, themes such as *absorptive capacity* and *impact* occupy more peripheral positions, indicating opportunities for future theoretical integration and conceptual refinement (Cobo et al., 2011). Collectively, the thematic maps reveal a heterogeneous yet structured field.

Figure 1d. Thematic Mapping of Green Innovation Research-4 (Centrality–Density Diagram)

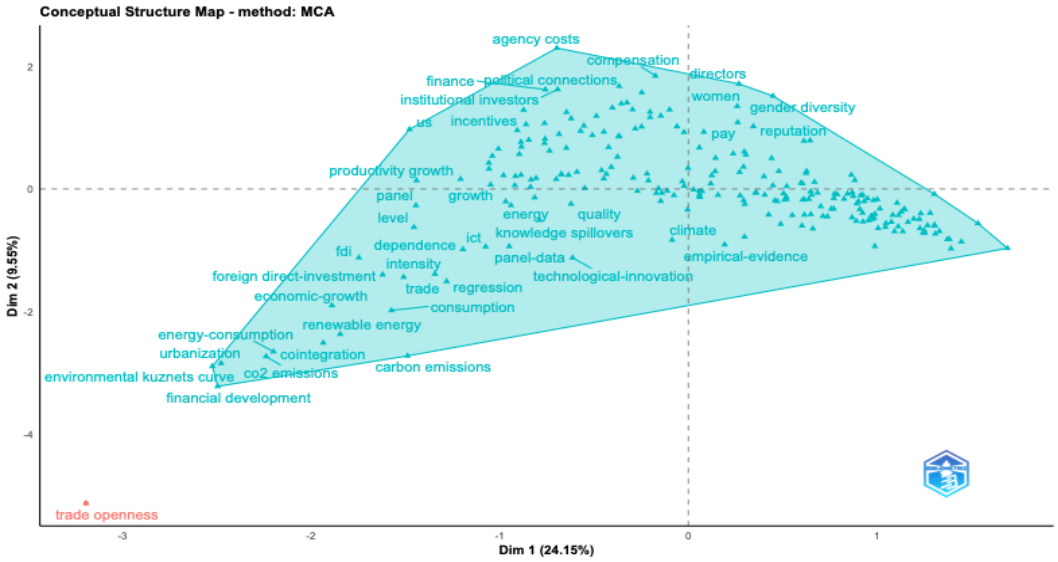


3.1.2. Multiple Correspondence Analysis (MCA) (R-Based)

The results of the MCA indicate that the green innovation literature is structured around multiple conceptual axes (see Figure 2). In the conceptual structure map, the central positioning of concepts such as technological innovation, knowledge diffusion, growth, and energy suggests that these themes form a core structure linking different research streams within the literature (Aria & Cuccurullo, 2017; Greenacre, 2017). In contrast, concepts related to carbon emissions, renewable energy, energy consumption, and the

environmental Kuznets curve cluster together, indicating that studies focusing on environmental impacts and energy-related issues have developed a relatively distinct research stream. Moreover, the co-location of governance-related concepts—such as agency costs, institutional investors, gender diversity, and ownership structure—points to the presence of a separate conceptual axis emphasizing corporate governance and managerial dimensions within the green innovation literature. The literature thus reflects an interconnected but multi-layered conceptual structure (Donthu et al., 2021).

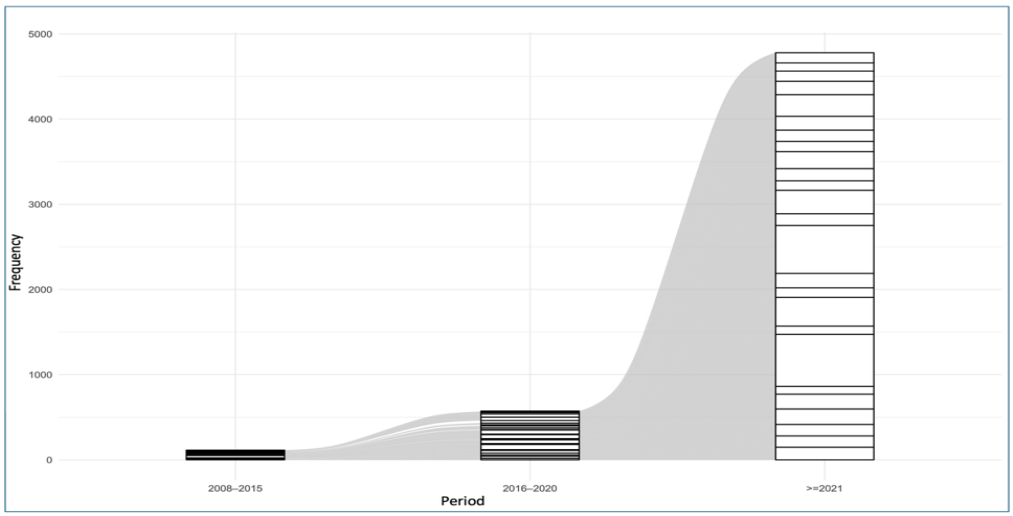
Figure 2. Conceptual Structure Map



3.1.3. Thematic Evolution (Sankey) Analysis (R-Based)

The thematic evolution analysis (see Figure 3) illustrates the temporal distribution of keywords and the continuity of thematic relationships within the green innovation literature. During the 2008–2015 period, the thematic structure remained relatively narrow, with a limited number of keywords and low flow intensity. Between 2016 and 2020, both the number of keywords and the volume of thematic flows increased markedly, indicating diversification of research topics. After 2021, thematic flows reached their highest intensity, with a strong concentration of keywords in this phase. At the same time, many themes introduced in earlier periods persisted, reflecting substantial thematic continuity over time.

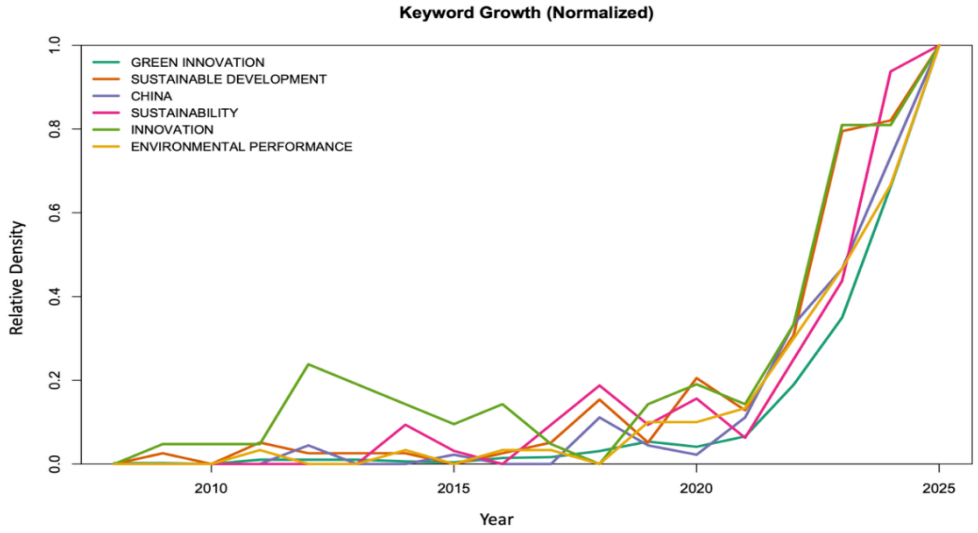
Figure 3. Thematic Evolution of Green Innovation Research (Sankey Diagram)



3.1.4. Keyword Growth Analysis (R-Based)

The keyword growth analysis (see Figure 4) reveals the relative developmental trajectories of prominent concepts within the green innovation literature over time. The findings indicate that the keyword "green innovation" exhibits a pronounced increase after 2015 and attains a central position in the literature in the post-2020 period. Similarly, the concept of sustainability demonstrates increasing visibility over time and becomes progressively more integrated with the green innovation theme. In contrast, the keyword "sustainable development" appears more prominently in earlier studies, while its relative prominence declines in subsequent periods. Concepts such as environmental performance and innovation have attracted growing attention in recent years; however, they do not display growth trajectories as central as those of green innovation and sustainability. In addition, the keyword "China" emerges as prominent during specific periods; nevertheless, rather than representing a conceptual theme, it primarily reflects a contextual research focus within the literature. The literature increasingly converges around sustainability and performance-oriented perspectives.

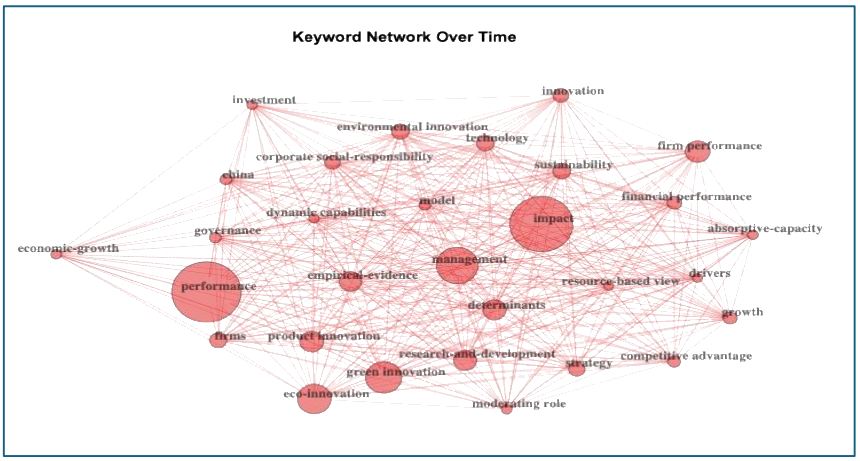
Figure 4. Keyword Growth Analysis



3.1.5. Time-Based Keyword Network Analysis (R-Based)

The time-based keyword network analysis (see Figure 5) shows that co-occurring concepts in the green innovation literature form a dense interaction network. Performance, impact, and management appear as the most densely connected nodes in the network. Core concepts such as green innovation, eco-innovation, sustainability, and environmental innovation maintain strong linkages with performance and strategy-related themes. Outcome-related variables, including firm performance, financial performance, competitive advantage, and growth, are directly connected to green innovation themes. In addition, concepts such as absorptive capacity, dynamic capabilities, and the resource-based view indicate the integration of organizational capability perspectives within the field.

Figure 5. Time-Based Keyword Network Analysis

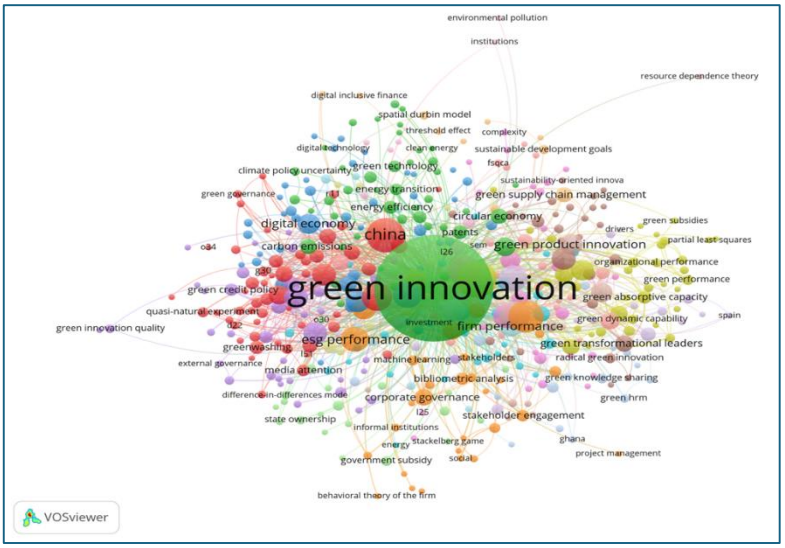


3.2. Key Concept Networks

3.2.1. Author Keyword Co-occurrence Analysis (VOSviewer-Based)

Based on the co-occurrence analysis (see Figure 6) of author keywords, a network map was constructed by applying a threshold of a minimum of four occurrences per keyword. Accordingly, 469 keywords meeting this criterion were included in the analysis. Co-occurrence analysis is a widely used method for visualizing the thematic structure of a research field and the relationships among key concepts (Callon et al., 1983; Zupic & Čater, 2015). Within this framework, a total of 4,843 links were identified, and the total link strength was calculated as 8,255. The keywords were grouped into 18 distinct clusters based on their co-occurrence relationships. Accordingly, the keyword network is primarily dominated by clusters related to environmental regulation, firm performance outcomes, ESG and green finance mechanisms, digital transformation, and green supply chain management, reflecting the main thematic pillars structuring the field. The results indicate that the keyword “green innovation” occupies a central position in the literature, with 1,186 occurrences and a total link strength of 2,455. The concept functions as a core connector within the literature (van Eck & Waltman, 2010). In particular, the strong co-occurrence relationships established with concepts such as sustainable development, environmental performance, environmental regulations, eco-innovation, corporate social responsibility, and digital transformation point to the multidimensional and interdisciplinary nature of the green innovation research field.

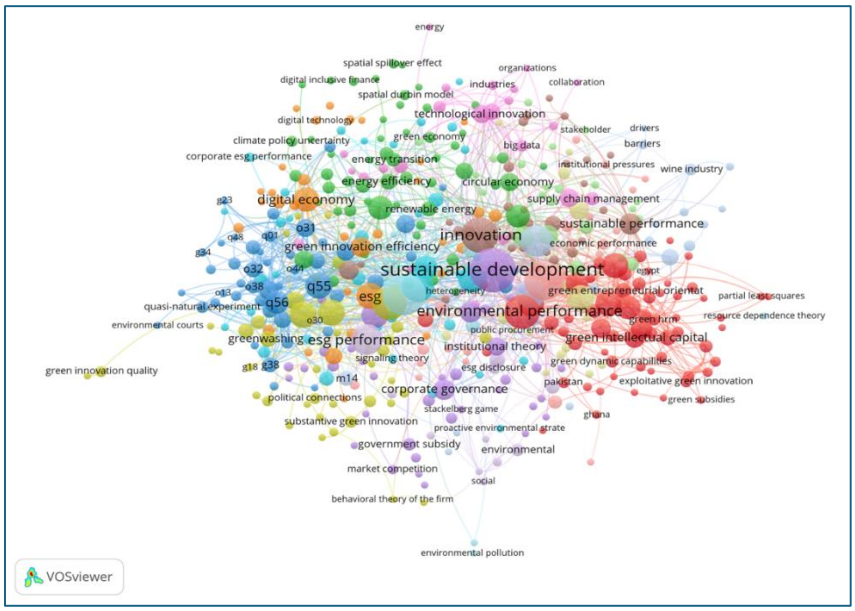
Figure 6. Author Keyword Co-occurrence Analysis



3.2.2. Keyword Co-occurrence Analysis Excluding "Green Innovation" (VOSviewer-Based)

In the second stage of the author keyword co-occurrence analysis (see Figure 7), the focal concept of "green innovation" was excluded from the network in order to prevent its dominant position from overshadowing the relationships among other concepts. This methodological choice enabled greater visibility of alternative themes, highlighted conceptual diversity, and allowed for a clearer examination of interdisciplinary orientations within the literature. Within this framework, the network map was constructed based on 468 keywords and 4,416 links. The results indicate that "sustainable development" emerges as the most frequently occurring concept, with 142 occurrences and a total link strength of 414. This keyword is followed by "China," "sustainability," "innovation," Q55 (the JEL classification code referring to technological innovation in the context of environmental economics), "environmental performance," "environmental regulations," and "digital transformation." In addition, concepts such as eco-innovation, ESG performance, corporate social responsibility, green finance, and financial constraints are also positioned as prominent themes within the literature. Overall, these findings demonstrate that green innovation research is not confined solely to an environmental sustainability focus; rather, it constitutes a multidimensional research domain that is strongly connected to financial structures, governance mechanisms, corporate responsibility, and digitalization.

Figure 7. Keyword Co-occurrence Analysis Excluding "Green Innovation"



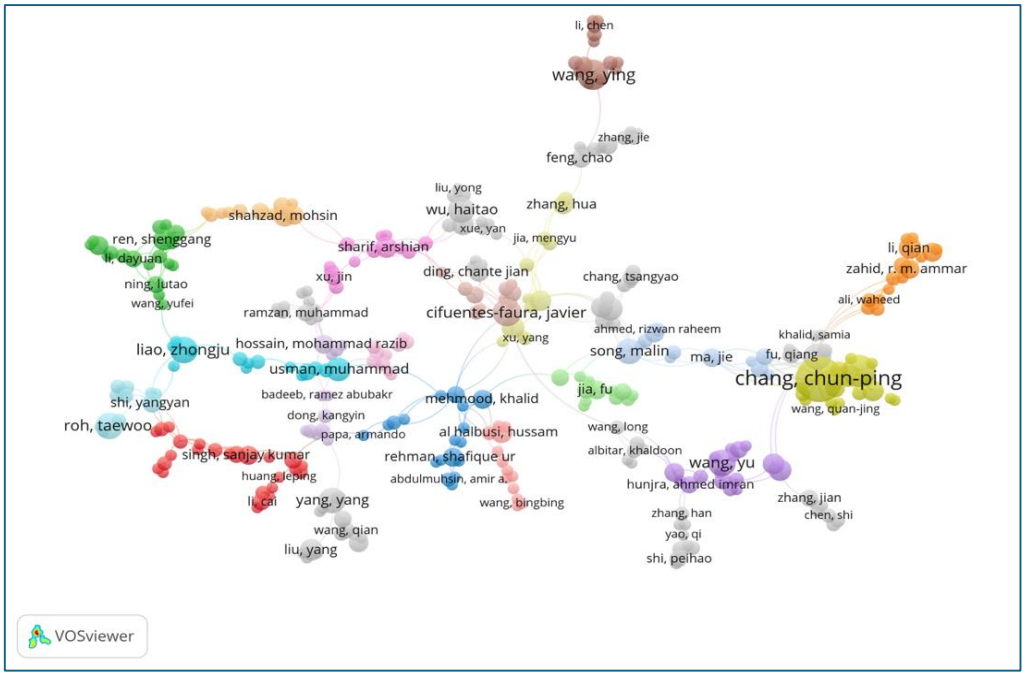
3.3. Social Structure and Actors

3.3.1. Co-authorship Analysis (VOSviewer-Based)

To examine patterns of collaboration among authors, a co-authorship analysis (see Figure 8) was conducted using VOSviewer. Co-authorship networks make visible the social interactions and collaborative structures underlying academic knowledge production (Newman, 2001; Zupic & Čater, 2015). In the analysis, authors with at least five publications and a minimum of two citations were selected as threshold criteria. Among the 6,277 authors meeting these criteria, 72 authors were initially identified for inclusion. However, the number of authors exhibiting actual co-authorship ties was limited, resulting in a network structure consisting of 15 authors, 5 clusters, 22 links, and a total link strength of 63. This network configuration suggests that dense and sustained collaboration networks within the green innovation literature remain relatively limited. Within the co-authorship map, C. P. Chang emerges as the most central author in terms of collaboration, with 29 publications and a total link strength of 29. Chang is followed by G. F. Feng and J. Wen

in terms of link strength. In contrast, several authors with high publication and citation counts are observed to maintain relatively weak collaborative ties within the network. These findings indicate that academic productivity and collaboration intensity do not always exhibit a direct relationship in the green innovation literature, and that collaborative activities tend to cluster around specific groups of authors rather than forming broadly interconnected networks (Acedo et al., 2006; Wasserman & Faust, 1994).

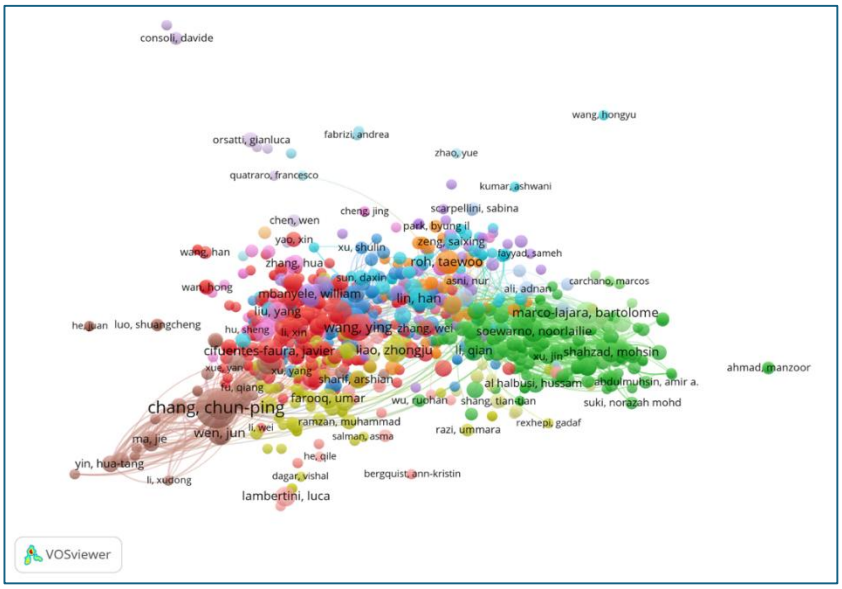
Figure 8. Co-authorship Analysis



3.3.2. Author Citation Analysis (VOSviewer-Based)

While co-authorship analysis reveals collaboration patterns, author citation network analysis focuses on the structural characteristics of knowledge flows and intellectual interactions within the literature (Price, 1965; Zupic & Čater, 2015). In the citation network analysis (see Figure 9), threshold criteria of a minimum of two publications and at least five citations were applied for authors to be included. Among the 6,277 authors meeting these criteria, 907 authors were initially selected for analysis. However, since not all of these authors were connected through citation relationships, the final network was constructed based on 343 authors who had at least one citation link. The resulting network consists of 29 clusters, with a total of 627 links and an overall link strength of 916. The findings indicate that C. P. Chang occupies the most central position in the citation network in terms of both productivity and connectivity, with 29 publications, 1,706 citations, and a total link strength of 61. In contrast, several highly cited authors—such as Y. S. Chen; S. K. Singh; and R. M. Dangelico—exhibit relatively lower link strength values and are not positioned at the core of the network. This finding suggests that there is not always a linear relationship between an author's total citation count and their structural centrality within the citation network (Leydesdorff, 2007; Wasserman & Faust, 1994). Overall, the author citation network analysis demonstrates that knowledge flows in the green innovation literature are shaped not solely by individual citation volume, but also by the relational structure and thematic proximities among authors.

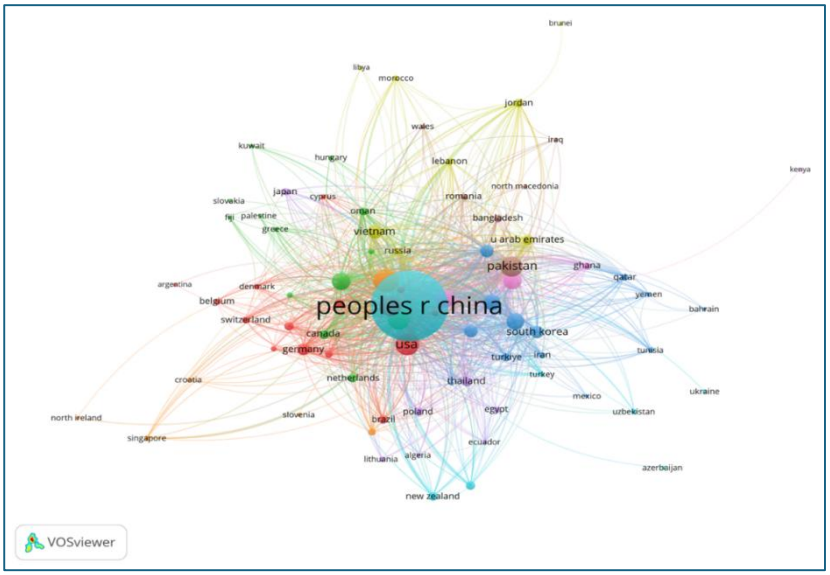
Figure 9. Author Citation Analysis



3.3.3. Country Citation Analysis (VOSviewer-Based)

In the country-level citation analysis (see Figure 10), 79 countries were included in the analysis out of 97 countries that met the threshold criteria of at least two publications and a minimum of five citations. Country-based citation analyses reveal how scientific knowledge is distributed globally and identify which countries occupy central positions of influence within the literature (Glänzel & Schubert, 2001; Zupic & Čater, 2015). Among these countries, a total of 1,809 citation links were identified, with an overall link strength of 36,243. In terms of citation counts, China emerges as the most central country in the literature, with 51,852 citations and a total link strength of 16,747. China is followed by Taiwan, Italy, the United Kingdom, and the United States. Examination of the network structure indicates that China occupies a position close to the center of the network and maintains strong citation relationships with a large number of countries. In addition, the prominence of developing countries such as Pakistan and Malaysia, which exhibit relatively high link strength values, suggests that scientific production in the green innovation literature is not confined solely to developed economies. Rather, the field is evolving within an expanding international collaboration network (Wagner et al., 2015). Overall, these findings indicate that green innovation has increasingly become a globally organized research field, albeit one that remains concentrated around a set of influential countries.

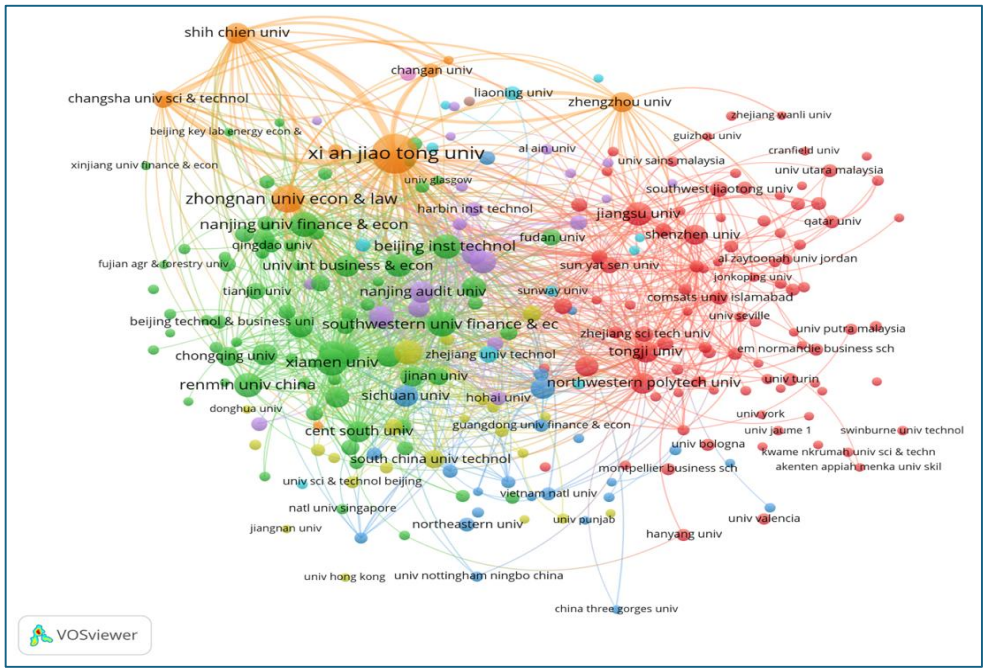
Figure 10. Country Citation Analysis



3.3.4. Organizational Citation Analysis (VOSviewer-Based)

In the bibliometric network analysis of organizational citations (see Figure 11), a total of 256 institutions meeting the threshold criteria of at least five publications and a minimum of ten citations were identified. Institution-level citation analyses reveal how academic knowledge production is concentrated within specific organizational hubs and the extent of these institutions' influence within the literature (Glänzel, 2001; Zupic & Čater, 2015). According to the findings, Xi'an Jiaotong University emerges as the most prominent institution in terms of both research output and citation impact, with 97 publications and 3,284 citations. This institution is followed by Southwestern University of Finance and Economics (40 publications, 3,002 citations), Xiamen University (45 publications, 2,966 citations), and Ilma University (13 publications, 2,847 citations). Within the inter-institutional network structure, the total link strength was calculated as 28,625, and a total of 12,549 links were identified. The network map indicates that institutions are grouped into nine distinct clusters. The results further demonstrate that Chinese-based universities, in particular, occupy central positions in the global literature in terms of both collaboration and citation relationships. Overall, this structure highlights the concentration of research production and citation influence within specific institutional and geographic centers in the green innovation literature, while also making visible the direction of academic collaborations and the distribution of citation interactions across institutions.

Figure 11. Organizational Citation Analysis



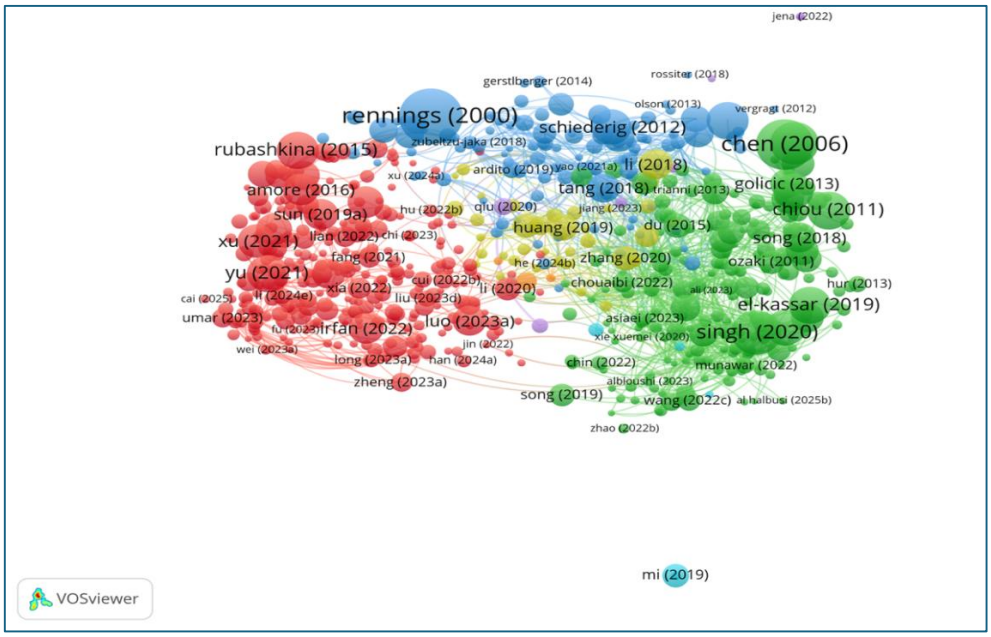
3.4. Intellectual Structure

3.4.1. Document Bibliographic Coupling Analysis (VOSviewer-Based)

To examine intertextual relationships among publications in the green innovation literature, a bibliographic coupling analysis (see Figure 12) was conducted by applying a minimum citation threshold of 30. Of the 2,469 publications meeting this criterion, 657 documents were included in the analysis. Bibliographic coupling is an analytical approach that reveals contemporary content-based proximity among publications by identifying shared reference sets (Boyack & Klavans, 2010; Kessler, 1963). As a result of the analysis, 93,463 links and a total link strength of 206,282 were identified among 656 documents. The resulting network map indicates that publications are structured into eight clusters based on their content similarity. The findings reveal that highly cited publications do not necessarily exhibit the strongest bibliographic

coupling ties. For instance, seminal works such as Rennings (2000), Chen (2006), and Nidumolu et al. (2009), despite receiving high citation counts, do not appear among the publications with the highest total link strength in the bibliographic coupling network. In contrast, the study by Duque-Grisales and Aguilera-Caracuel (2020), although having a relatively lower citation count, establishes strong bibliographic coupling relationships within the literature, as reflected by its high total link strength. Similarly, more recent studies such as Khan et al. (2021) and Huang et al. (2022) also stand out with high link strength values. These findings indicate that in bibliographic coupling analysis, not only citation counts but also the relationships established through shared reference sets play a critical role in identifying the current structure of the literature and delineating the research front (van Eck & Waltman, 2010; Zupic & Čater, 2015). Moreover, the results demonstrate that recent studies in the green innovation literature tend to concentrate around specific thematic clusters, highlighting the dynamic and evolving nature of the field.

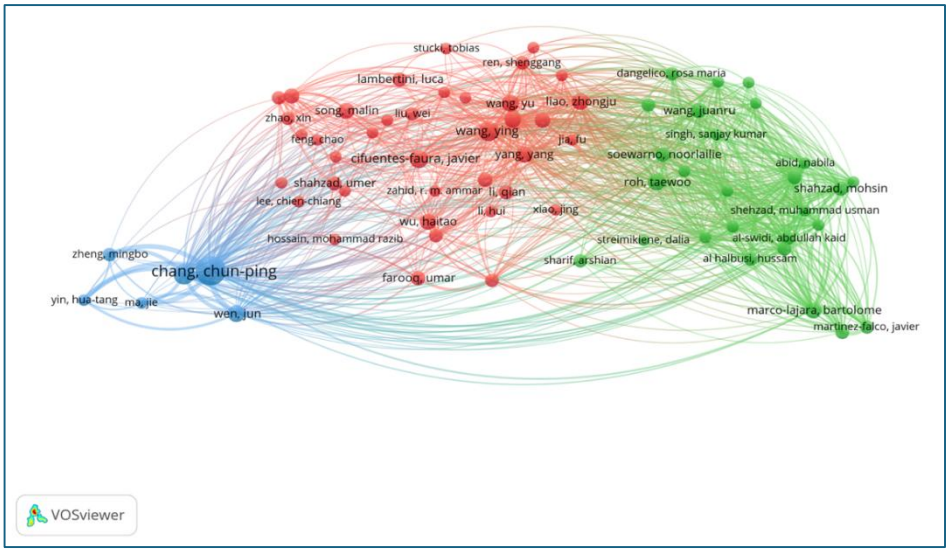
Figure 12. Document Bibliographic Coupling Analysis



3.4.2. Author Bibliographic Coupling Analysis (VOSviewer-Based)

In the bibliographic coupling analysis (see Figure 13) conducted at the author level, threshold criteria of a minimum of five publications and at least ten citations were applied, resulting in the inclusion of 72 authors who met these requirements. Bibliographic coupling is an analytical approach that reveals contemporary intellectual proximity among authors based on the extent to which their publications rely on similar reference sets (Boyack & Klavans, 2010; Kessler, 1963). Within the constructed network map, a total of 2,512 links were identified, and the overall link strength was calculated as 111,786. According to the results, C. P. Chang emerges as the most central author in the bibliographic coupling network, with 29 publications, 1,706 citations, and a total link strength of 15,919. Chang is followed by G. F. Feng (15 publications, 1,008 citations, 10,253 total link strength), B. Marco-Lajara (9 publications, 173 citations, 6,324 total link strength), J. Aftab (6 publications, 416 citations, 6,312 total link strength), and J. Wen (10 publications, 429 citations, 5,772 total link strength). The high degree of shared references between these authors and other studies in the literature indicates that they are strongly integrated into the current research front of green innovation research (van Eck & Waltman, 2010; Zupic & Čater, 2015). Overall, the author-level bibliographic coupling network makes visible the patterns of knowledge flow and thematic proximity among researchers, pointing to a clustered and interdisciplinary intellectual structure within the green innovation literature.

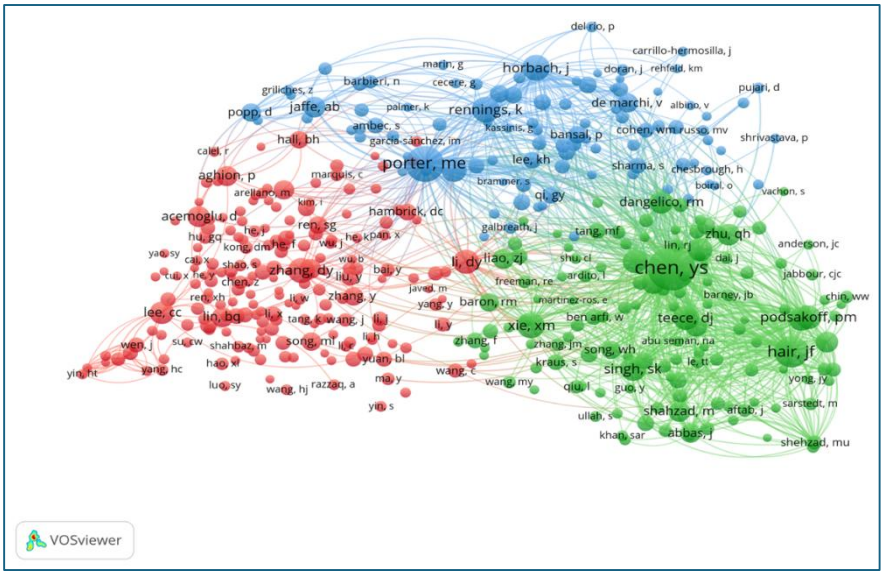
Figure 13. Author Bibliographic Coupling Analysis



3.4.3. Author Co-citation Analysis (VOSviewer-Based)

In the author-level co-citation analysis (see Figure 14), authors who had received at least 50 citations were considered, resulting in the inclusion of 419 authors in the analysis. The analysis identified a total of 73,273 links among authors, with an overall link strength of 574,974. The resulting co-citation network is structured into three distinct clusters. Co-citation analysis indicates that the frequent joint citation of particular authors reflects the existence of shared intellectual foundations and similar theoretical reference frameworks within the literature (Small, 1973). According to the findings, Y. S. Chen stands out as one of the most central authors in the co-citation network, with 1,209 citations and a total link strength of 31,715. Chen is followed by M. E. Porter (830 citations, 18,509 link strength), J. F. Hair Jr. (621 citations, 15,981 link strength), K. Rennings (425 citations, 11,568 link strength), and J. Horbach (419 citations, 11,561 link strength). The frequent co-citation of these authors across different studies suggests that the green innovation literature is grounded in a multi-layered theoretical backbone shaped around environmental regulations, innovation performance, and methodological frameworks (Ramos-Rodríguez & Ruíz-Navarro, 2004; Zupic & Čater, 2015). Overall, the results indicate that the green innovation literature exhibits a structure characterized by theoretical diversity, with strong co-citation clusters forming around specific thematic domains.

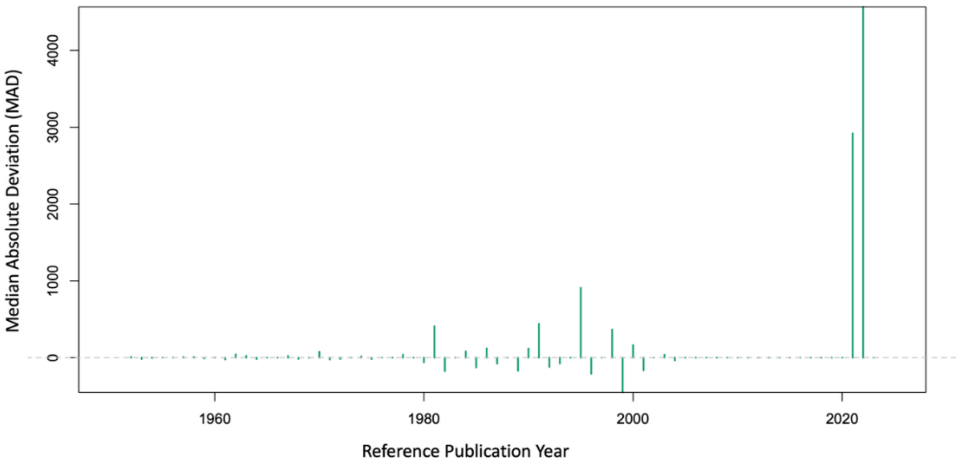
Figure 14. Author Co-citation Analysis



3.4.4. Reference Publication Year Spectroscopy (RPYS) Analysis (R-Based)

The reference publication year spectroscopy (RPYS) analysis (see Figure 15), indicates the presence of marked variations in the publication years of cited references within the green innovation literature (Marx et al., 2014; Thor et al., 2016). The RPYS graph shows that deviations from the median citation count remain limited for most years; however, certain years exhibit sharp and pronounced positive deviations. This pattern suggests that the citation distribution across years is not homogeneous (Khasseh & Mokhtarpour, 2016). In particular, distinct peaks are observed in the early 2000s and the mid-2010s. These periods stand out in terms of citation intensity and occupy a central position in the reference structure of the analyzed literature. By contrast, the years between these peaks display citation levels closer to the median line, indicating a more balanced distribution of referenced publications. Overall, these findings demonstrate that the reference structure of the green innovation literature is concentrated around specific publication years, and that the intellectual development of the field has been shaped predominantly by studies published during these key periods.

Figure 15. Reference Publication Year Spectroscopy



4. Discussion and Conclusion

The bibliometric findings show that green innovation research is not only expanding in volume but also developing a diverse and evolving intellectual structure marked by global asymmetries. An integrated analysis of thematic mapping, MCA, thematic evolution, and network structures indicates that the field converges around several core concepts while simultaneously expanding into new research directions. Rather than offering a purely descriptive overview, this study demonstrates how the structure and orientation of the field are transforming over time.

The thematic map and MCA results indicate that the field's conceptual structure is multi-axial rather than centered on a single dominant theme. Core concepts such as green innovation, innovation, performance, and impact occupy central positions, reflecting a growing emphasis on outcome-oriented perspectives. At the same time, the strong centrality of motor themes including eco-innovation, competitive advantage, and strategy suggests that green innovation is framed not only as an environmental initiative but also as a strategic driver of competitiveness. This pattern is consistent with prior research emphasizing strategic orientation and competitive advantage in green innovation studies (Akbari et al., 2022; Albort-Morant et al., 2017). Findings of this research build on this literature by showing how these themes are structurally interconnected within the publication network and by clarifying their prominence through centrality measures.

The field's interdisciplinary nature is evident in the conceptual structure map, which shows environmental, technological, and managerial topics forming distinct yet interconnected clusters. This pattern lends some support to concerns about "conceptual fragmentation" in the literature (Ouardi & Boungab, 2025). However, the observed diversity does not appear arbitrary. Rather than indicating incoherent divergence, the presence of multiple thematic clusters reflects different research perspectives engaging with a shared problem domain.

In addition to these structural patterns, the temporal evolution of the field demonstrates a clear progression of research themes. Early studies predominantly focused on problem-defining issues such as environmental regulations, carbon emissions, and energy consumption—reflecting the field's initial emphasis on regulatory pressures and environmental challenges. Over time, attention shifted toward technological innovation and eco-innovation, broadening the scope beyond compliance to include innovation-driven solutions. In the most recent period, green innovation scholarship has converged on a more holistic perspective that links innovation activities with firm performance, competitiveness, and sustainable value creation. The RPYS analysis further indicates that this shift was driven by a limited number of seminal works. Rather than developing through steady accumulation alone, the field appears to have advanced through distinct theoretical turning points.

The global expansion of green innovation research has not eliminated the concentration of knowledge production within specific hubs. Co-authorship and citation patterns show that a limited number of countries and institutions continue to dominate publication output and citation impact, reflecting persistent geographical asymmetries. Country-level citation data, for example, position China at the center of the network, illustrating both the field's globalization and the continued concentration of influence in particular national contexts. At the same time, a growing number of countries are contributing to the literature, indicating gradual diversification beyond traditional scientific centers. Importantly, citation volume alone does not determine structural centrality. The field is shaped both by highly cited foundational works and by collaborative network dynamics.

The analysis of citation linkages, including co-citation and bibliographic coupling, reveals a dual-layered intellectual structure. On one level, highly cited foundational works constitute the field's theoretical backbone. On another, more recent studies, even those with modest citation counts, occupy central positions within emerging thematic clusters. This pattern suggests that influence depends not only on citation volume but also on a publication's structural role within the evolving research network. Newer studies can shape the field by connecting or advancing emerging themes, even before accumulating high citation counts. Overall, the field progresses through both established theoretical foundations and the integration of new research fronts.

Beyond mapping structural patterns, these findings refine several assumptions in the existing literature. First, while green innovation research is often described as conceptually fragmented, the network structure reveals an underlying integration around performance, competitiveness, and sustainability outcomes. The diversity of themes therefore reflects differentiation rather than theoretical incoherence. Second, the results reinforce the view that the field has moved beyond a regulation-centered paradigm. The centrality of strategy and performance-related themes indicates that green innovation is increasingly positioned as a driver of competitive advantage rather than merely a response to environmental pressure. Third, the findings challenge the assumption that citation volume alone determines intellectual influence. By showing that structural centrality does not always align with citation counts, the study highlights the importance of network positioning and thematic bridging in shaping research fronts.

Taken together, these findings reposition green innovation research as an integrated yet multi-layered field in which environmental, technological, and managerial perspectives converge around competitiveness and value creation. *Theoretically*, the study challenges the view of fragmentation and clarifies the structural logic underlying the field's development. It demonstrates that green innovation has evolved from a regulation-driven discourse into a performance-integrated strategic domain. *Methodologically*, the combined use of thematic, temporal, and network-based bibliometric techniques

provides a multidimensional perspective that captures both consolidation and differentiation within the literature. By offering this integrated and relational explanation, the study advances a more dynamic understanding of how intellectual influence and research fronts emerge in green innovation research.

This bibliometric review offers a comprehensive overview of the green innovation literature by mapping its conceptual themes, knowledge networks, and evolution over time. Our findings show that what began as a narrowly focused environmental discourse has transformed into a broad interdisciplinary domain that interweaves sustainability-oriented innovation with core business and economic concerns (such as firm competitiveness and performance). The field's knowledge base remains anchored by a set of core concepts and influential works, yet it continually branches out into new topics, demonstrating a clear pattern of thematic expansion. Overall, this work provides a holistic perspective on how green innovation research has developed, and it identifies emergent areas that can guide future inquiries in the field.

In practical terms, the findings also offer several implications. For managers, green innovation should be integrated into competitive strategy rather than treated as a compliance-oriented activity. Strengthening the linkage between green innovation and firm performance, as well as aligning governance structures and ESG practices, appears critical for sustained value creation. For policymakers, regulatory frameworks should move beyond compliance enforcement toward enabling innovation and supporting institutional capabilities that foster green transformation. For researchers, future studies could advance the field through comparative country analyses, sector-specific investigations, mixed-method research designs, and deeper exploration of the governance–performance nexus.

The study has certain limitations that point toward directions for further research. First, our analysis was confined to Web of Science-indexed journal articles, which means it may have omitted relevant work in books, conference proceedings, or other databases. Future research could broaden the scope by incorporating such sources to capture a more comprehensive picture of the field. Second, while bibliometric methods effectively reveal quantitative patterns and relationships, they offer limited insight into the qualitative content and context of the literature. Researchers might address this gap by complementing bibliometric analysis with qualitative approaches – for example, in-depth case studies or content analysis – to gain deeper understanding of the themes and impacts identified. Additionally, comparative studies across different countries, regions, or industry sectors would help mitigate the geographic concentration observed in the current literature and test the generalizability of our findings. By pursuing these avenues, subsequent research can build on our results, overcome present limitations, and further enrich the understanding of green innovation in business and economics.

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