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A Bibliometric Perspective of the Green Transition Within the Framework of Sustainable Development

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Abstract

The green economy and the broader green transition have become central themes in global sustainability efforts, reflecting a strategic shift in addressing environmental challenges through economic transformation. This study provides a systematic bibliometric analysis of 1014 peer-reviewed publications indexed in Scopus on the green transition within the framework of sustainable development, covering the period 1990–2024. The findings show a rapid growth in research output after 2015, culminating in 360 publications in 2024. China, Italy, and the Russian Federation emerge as the most active contributors, while collaboration networks reveal both established partnerships and emerging participation from Central and Eastern Europe. Influential authors include Mahmood Haider and Fabio Iraldo, and major publication outlets are the Journal of Cleaner Production, Sustainability (Switzerland), and Ecological Economics. Four thematic clusters—renewable energy, climate policy, circular economy, and green innovation—highlight dominant research trajectories and persistent knowledge gaps. By mapping authors, sources, keyword co-occurrences, and citation structures, this study offers a structured foundation for future research and a clearer understanding of how the green transition is conceptualized within sustainability scholarship.

Keywords: green economy; green transition; sustainable development; bibliometric analysis

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1. Introduction

Amid intensifying environmental pressures and the growing urgency of climate change, the concept of green transition has become central to global sustainable development discourse. It represents a fundamental shift in how economies, societies, and institutions operate, aiming to reduce ecological degradation, improve resource efficiency, and ensure equity for present and future generations [1]. This transition requires systemic transformations across energy, industry, governance, finance, and education, reflecting the interconnected nature of sustainability challenges [2–4]. Closely linked to the broader concept of the green economy, the green transition promotes growth that is ecologically sustainable, socially inclusive, and economically resilient [5–10]. It seeks to decouple economic development from environmental harm by aligning innovation, investment, and public policy with long-term sustainability goals [11–15].

The green transition is not an isolated process, but one deeply integrated in the efforts to achieve the Sustainable Development Goals (SDGs), requiring an inter- and transdisciplinary approach. Accordingly, over the past two decades, scholarly interest in green

transition has expanded rapidly, spanning disciplines such as environmental science, economics, public policy, and technology [16–19]. The literature highlights the importance of transitioning to renewable energy, fostering green finance, reforming urban mobility, and strengthening environmental governance [20–25]. This suggests a growing recognition of the social dimensions of sustainability, particularly community resilience, social equity, and participatory governance [26–28]. Yet, despite the growth of this body of knowledge, there is limited systematic understanding of how research in this area is structured, how it evolves, and which themes, actors, and institutions are most influential [29–31].

In this context, bibliometric analysis has emerged as a valuable tool to map the scientific landscape, track knowledge trends, and identify gaps. By analyzing co-authorship networks, citation patterns, and thematic clusters, bibliometrics provides insights into how the green transition is conceptualized, who is shaping the discourse, and which directions future research may take [32–37]. This is particularly important as nations, institutions, and the private sector increasingly seek evidence-based pathways to navigate the complexities of green transformation, where the role of finance has become especially prominent [23,38] with the European sustainable finance package and ESG investment frameworks positioning the financial sector as a key enabler of green growth.

Hence, scholars have examined the potential of green financial instruments to direct capital toward environmentally responsible projects, manage climate risks, and encourage firms to integrate sustainability into core decision-making [39–43]. Similarly, studies have emphasized the relevance of energy transitions, design thinking, the sharing economy, and circular production models as integral components of a sustainable economic future [44–46]. Moreover, comparative studies across countries, particularly in Central and Eastern Europe, have explored diverse challenges and policy responses in the shift to climate neutrality, underlining the need for tailored strategies, strong regulatory frameworks, and stakeholder engagement [47–50]. Therefore, the goal of green transformation is to abandon unsustainable practices and transition to a greener and more sustainable future [51].

With a view to accelerate the energy transition and meet international climate commitments, countries need to significantly accelerate the deployment of low-emission infrastructure, such as renewable energy networks and public transport. Countries can use a number of governance tools to help them achieve this, including an agile and efficient permitting system, increased stakeholder engagement and green public procurement. Keeping global temperatures within these limits and mitigating the risks of climate change require countries to accelerate their energy transition and become more energy efficient. Low-emission infrastructure is also important for strengthening domestic energy production [52–55].

A different category of research explores the sharing economy as a potential approach to promoting sustainable development. Using bibliometric analysis, it was found that few studies have highlighted collaborative and sustainable consumption, climate change and the bioeconomy in the sharing economy by country, such as renewable resources and business models, the circular economy and life cycle assessment, highlighting some important evidence from urban mobility services in China [56–58]. In contrast, the research conducted by Niță and Stoicuța (2025) examined the influence of primary energy consumption, both renewable and non-renewable per capita, as well as gross fixed capital formation per capita upon sustainable economic growth [45]. The analysis of data spanning 33 years (1990–2022) was based on the CES-type functions and it has shown that only the rise in gross fixed capital formation per capita fueled economic growth in Romania, while enhancements in both renewable and no-renewable primary energy consumption per capita could be connected to the descendent tendencies in real GDP per capita. Thus, policymak-

ers should find ways to adjust low-carbon energy transition patterns to national frameworks' peculiarities in order to convert the renewable energy into a significant positive driver of economic development. Despite these advancements, significant gaps remain in understanding how research in the green transition field is distributed, the extent of interdisciplinary collaboration, and the emergence of new conceptual frontiers. A clearer picture of the scientific ecosystem surrounding the green economy is essential for informing academic inquiry, policy design, and practical implementation. Hence, the purpose of this study is to provide a bibliometric analysis of the green transition within the framework of sustainable development, with a view to uncovering its intellectual structure and thematic evolution. Accordingly, this study seeks to achieve the following objectives:

1 Identify and analyze the volume and dynamics of scientific publications related to the green transition in the context of sustainable development during the period 1990–2024;
2 Determine the most influential sources and authors in the research field, as well as international collaboration networks;
3 Map emerging themes and research clusters through keyword and co-citation analysis;
4 Assess the interdisciplinary distribution of the literature, with a focus on contributions from fields such as energy, environment, economics, technology, and public policy.

From these objectives, the following research questions are derived:

1 How has research output on the green transition within the framework of sustainable development evolved over the period 1990–2024?
2 Who are the most influential authors, sources, and countries, and what are the patterns of international collaboration in this field?
3 What are the dominant themes, clusters, and knowledge structures shaping the research landscape?
4 To what extent is the literature on the green transition interdisciplinary, and which fields contribute most significantly?

The above objectives are achieved through a bibliometric analysis of literature on the green transition and green economy in the context of sustainable development. Drawing on data from the Scopus database and using VOSviewer, the analysis aims to uncover influential contributors, intellectual structures, and thematic trends that define the evolution of this field from 1990 to 2024. Consequently, it provides an evidence-based overview of scholarly engagement with one of the most pressing transformation agendas of our time, advancing understanding of how green transition research is unfolding and where it is headed. This study's novelty lies in its integration of fintech–natural resource linkages, emphasis on scholarship from underserved regions, and incorporation of circular economy aspects, which together provide fresh insights into the intellectual and practical evolution of the field. This study is divided into the following sections: Section 1 is dedicated to the introductory part of the research, addressing the presentation of the field and the objectives pursued. Section 2 describes in detail the research methodology employed. Section 3 brings forward the results of the bibliometric analysis. Section 4 highlights a series of findings related to the results obtained, as well as the limitations of the study. In the final part of the paper, the conclusions of the study are properly drawn and exposed.

2. Theoretical Framework

To provide a solid conceptual foundation for this study, we draw upon three established theoretical perspectives that together offer a comprehensive lens for interpreting the thematic clusters identified in the bibliometric analysis.

Ecological Modernisation Theory (EMT) frames the analysis by emphasizing the role of technological innovation, institutional reform, and policy development in promoting environmentally sustainable practices. EMT posits that environmental protection and economic growth are not necessarily in conflict, and that modernization processes can be leveraged to achieve sustainability objectives [59]. In the context of the present study, EMT provides a lens to understand how the emergence of sustainable technologies, eco-innovations, and green practices is reflected in the thematic clusters. This framework also helps to interpret the ways in which research in the field addresses systemic environmental challenges while fostering innovation.

The Multi-Level Perspective (MLP) on sustainability transitions complements EMT by offering a structured view of how change occurs across different scales. MLP distinguishes between three analytical levels: niches (where radical innovations emerge), regimes (the dominant socio-technical structures), and landscapes (macro-level trends and pressures) [2]. Applying MLP allows us to examine how emerging research themes correspond to niche innovations, how they challenge or interact with established regimes, and how broader societal or environmental trends shape these dynamics. This perspective is particularly useful for understanding the temporal and systemic dimensions of sustainability transitions, revealing patterns that might otherwise remain obscured in a bibliometric overview.

Innovation Systems Theory (IST) emphasizes the role of networks, knowledge flows, institutional support, and policy frameworks in shaping innovation outcomes. IST provides insight into how actors, organizations, and institutions interact to facilitate or constrain the development and diffusion of new technologies and practices [60]. By applying IST, we can interpret thematic clusters in terms of collaborative structures, knowledge exchange, and systemic capacity for innovation, highlighting the conditions that enable sustainable solutions to emerge and diffuse within different contexts.

Collectively, these three frameworks provide complementary lenses that situate the bibliometric findings within established scholarship. They allow for a deeper understanding of how the field not only reflects ongoing trends in sustainability research but also extends and challenges existing theoretical perspectives. By integrating EMT, MLP, and IST, this study enhances the interpretative depth of the bibliometric analysis and clarifies the scholarly significance of the emerging research themes, offering a more nuanced view of the dynamics shaping sustainable innovation.

3. Materials and Methods

This study employs a rigorous bibliometric methodology to systematically map and analyses the scholarly landscape concerning the green economy, green transition, and sustainable development [61]. Bibliometric analysis has become a widely accepted method in academic research to identify structural patterns, knowledge domains, and intellectual evolution within a research field [62]. It facilitates the extraction of quantitative and visual insights from large volumes of scientific literature, offering a macroscopic view of research developments, trends, and collaborations over time [8,12,16].

3.1. Research Design and Rationale

The study is designed as an exploratory quantitative analysis, grounded in bibliometric principles, and complemented by science mapping techniques. It aims to uncover:

- The growth trajectory of scholarly publications on green economy, green transition, and sustainable development;
- Core thematic clusters and emerging research trends;
- Authorial and institutional collaboration patterns;

- Influential articles, authors, and journals in the field.

This approach enables a comprehensive and objective understanding of how knowledge production in the domain has evolved across disciplines, geographies, and over time [63–65].

3.2. Data Source and Search Strategy

To ensure the academic integrity and comprehensiveness of the dataset, the Scopus database was selected. Scopus was chosen due to its extensive coverage of peer-reviewed literature across disciplines, particularly in environmental studies, sustainability, and interdisciplinary fields relevant to the green transition. Compared to Web of Science, Scopus indexes a larger number of journals, especially from Europe and emerging economies, which ensures broader representation of global scholarship [66]. In addition, Scopus provides detailed citation data and keyword indexing, making it highly compatible with bibliometric tools such as VOSviewer [67]. Although some bibliometric studies combine Scopus and Web of Science, prior research has shown substantial overlap between the two databases [68]. Given this overlap, and the comprehensive coverage offered by Scopus, the use of this database alone is considered sufficient to ensure robustness, representativeness, and reliability of the dataset for this study.

The search was conducted in April 2025 and encompassed a 35-year period (1990–2024) to capture longitudinal patterns in research output. This timeframe was intentionally selected to reflect the emergence and consolidation of global discourse on sustainable development, beginning with the 1992 United Nations Earth Summit and reinforced by key international milestones such as the 1997 Kyoto Protocol and the 2015 Paris Agreement [69–71]. Although publication activity during the early 1990s was relatively modest, including this formative period ensures historical completeness by situating the contemporary expansion of the field within its broader intellectual trajectory. This approach is consistent with prior bibliometric studies that have adopted extended time windows to contextualize thematic evolution, even when early years display sparse publication density. For example, Ref. [72] examined the evolution of green finance over a 31-year period (1990–2020), noting that the field remained incipient until the early 2000s and gained momentum after the Kyoto Protocol. Similarly, Ref. [73] analyzed the research landscape of energy transition and green finance by covering all works indexed up to August 2023, justifying the inclusion of less active early years to depict the long-term growth trajectory [74], in their bibliometric study of artificial intelligence and renewable energy transitions spanning 2000–2024, likewise included years with minimal or no publications, arguing that such coverage highlights the incremental development of the field from its inception. By following this precedent, the inclusion of the 1990–2024 timeframe in the present study offers a robust and historically grounded perspective, enabling a more comprehensive understanding of the intellectual and thematic progression in sustainability transitions.

The search string was carefully constructed by using Boolean operators and field codes to capture relevant articles:

- TITLE-ABS-KEY (green AND economy AND green AND transition AND sustainable AND development)
- AND PUBYEAR > 1991 AND PUBYEAR < 2025
- AND (LIMIT-TO (SUBJAREA, “ENVI”))
- OR LIMIT-TO (SUBJAREA, “SOCI”)
- OR LIMIT-TO (SUBJAREA, “ECON”)
- OR LIMIT-TO (SUBJAREA, “BUSI”)
- OR LIMIT-TO (SUBJAREA, “EART”)
- OR LIMIT-TO (SUBJAREA, “AGRI”)

- AND (LIMIT-TO (DOCTYPE, "ar"))
- OR LIMIT-TO (DOCTYPE, "re")
- AND (LIMIT-TO (LANGUAGE, "English"))

This strategy ensured coverage of interdisciplinary perspectives while maintaining a focus on peer-reviewed journal articles only, excluding conference proceedings, book chapters, editorials, and grey literature. The geographic scope was set to global to reflect a comprehensive institutional and regional diversity in sustainability research. English was used as the language filter to ensure standardization and replicability [29].

3.3. Inclusion and Exclusion Criteria

The selection of documents for this study was guided by well-defined inclusion and exclusion criteria to ensure relevance, quality, and consistency with the study's objectives. To be included in the final dataset, documents had to meet the following conditions: they must be peer-reviewed journal articles or review papers; published between 1990 and 2024; written in English; and indexed under subject areas directly related to the research focus, namely Environmental Science, Social Science, Economics, Econometrics and Finance, Business, Management and Accounting, Earth and Planetary Sciences, and Agricultural and Biological Sciences. Furthermore, all selected articles were required to have a clear thematic focus on at least one of the following concepts: green economy, green transition, or sustainable development.

Articles were excluded if they were duplicate records, lacked essential metadata (such as author information, institutional affiliation, or keywords), or were categorized as non-journal documents (e.g., conference proceedings, editorials, book chapters, or working papers). Additionally, non-English publications and articles that fell outside the selected subject areas or did not explicitly align with the conceptual framework of the study were also removed from the dataset.

The initial search retrieved 2372 documents. After filtering based on inclusion and exclusion criteria, 1014 articles were retained for final analysis.

3.4. Data Pre-Processing

The dataset was exported from Scopus in CSV format. Data cleaning was conducted using Microsoft Excel to standardize metadata such as author names (e.g., resolving inconsistencies in spelling and initials), institutional affiliations and keyword formatting. Special attention was given to harmonizing synonymous keywords to ensure semantic consistency during co-occurrence analysis.

3.5. Analytical Tools and Techniques

The cleaned dataset was imported into VOSviewer (version 1.6.20), a widely recognized software tool for bibliometric visualization and network analysis. Five core analyses were conducted to extract meaningful insights from the dataset.

First, a descriptive analysis was carried out to explore the temporal evolution and disciplinary distribution of publications, providing an overview of how scholarly interest in green economy, green transition, and sustainable development has developed over time. Second, a co-authorship analysis was conducted to identify collaborative networks among researchers, offering insights into patterns of academic cooperation and the diffusion of knowledge across geographic boundaries. Third, a keyword co-occurrence analysis was performed to uncover dominant thematic areas and to detect emerging research trends within the field. Fourth, a citation analysis was undertaken to determine the most influential publications and to trace the development of intellectual structures and impact pathways in the literature. Finally, source title analysis was conducted to assess the distri-

bution of scholarly output across journals and to identify the most influential and active publication outlets in the field.

To ensure analytical clarity and minimize visual noise, network maps were generated using defined thresholds, such as selecting only those keywords that appeared at least five times within the dataset. This filtering allowed the analysis to concentrate on high-frequency terms and authors that shape the core of the research domain. The clustering algorithms embedded within VOSviewer facilitated the identification of distinct thematic groupings, revealing the density and structure of knowledge domains as represented by co-authorship, co-citation, and keyword clusters. This bibliometric systematic review follows PRISMA 2020 guidelines [75] (Supplementary materials). Figure 1 presents the PRISMA framework of the bibliometric process adopted in this study, illustrating the methodological workflow from data extraction to network visualization.

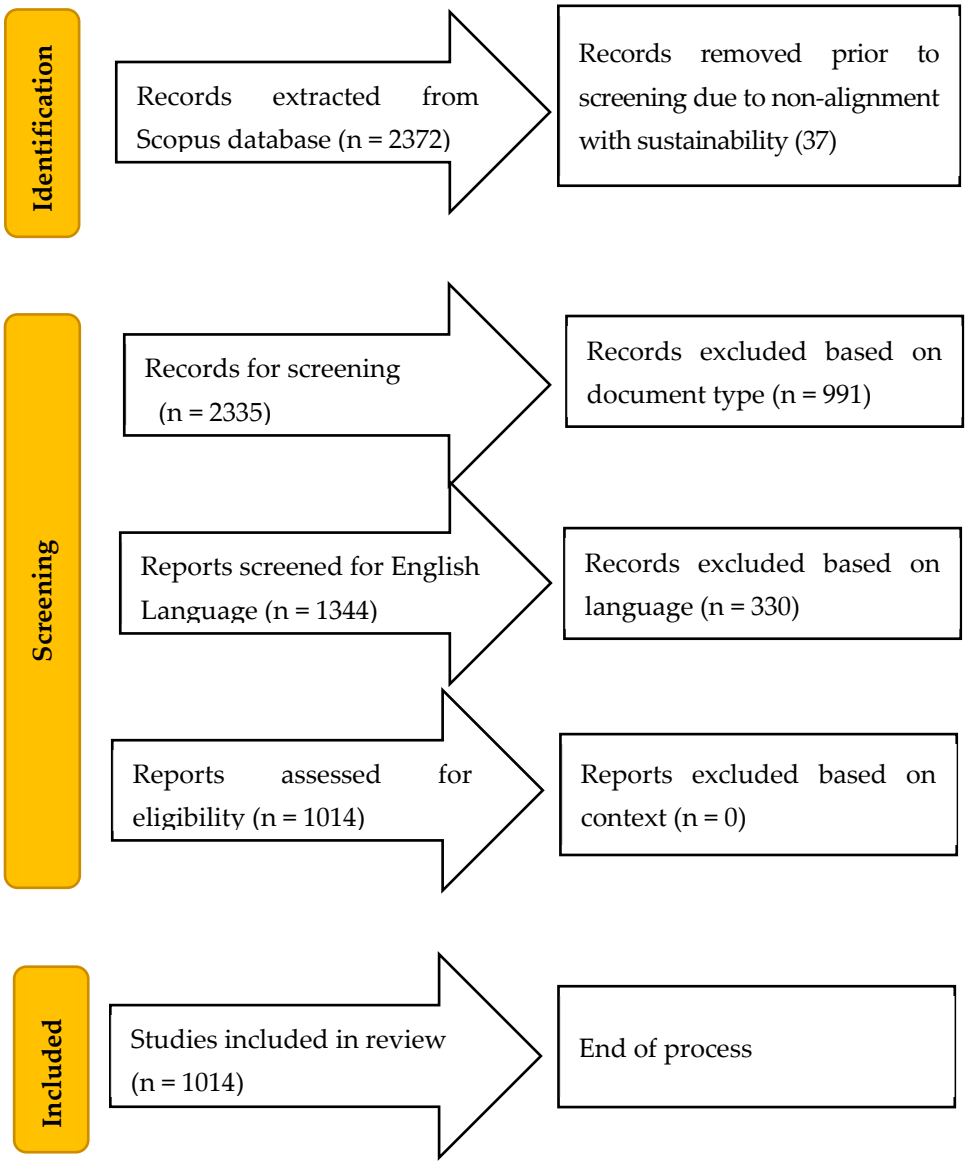


Figure 1. PRISMA flow diagram illustrating the systematic selection process of publications for the bibliometric analysis, highlighting the screening and inclusion steps that resulted in the final dataset.

4. Results

4.1. Descriptive Analysis

Prior to conducting the bibliometric mapping, a descriptive analysis was undertaken to explore the temporal and disciplinary evolution of the literature on the green economy, green transition, and sustainable development. This preliminary step helps contextualize the bibliometric findings by providing foundational insights into publication trends.

Using Microsoft Excel, the bibliographic data extracted from Scopus was analyzed in terms of publication year. The distribution of publications over time, as illustrated in Figure 2, indicates a significant upward trajectory in research output, particularly from the mid-2000s onwards. From a modest baseline in the early 1990s, scholarly attention has markedly increased, with publication peaks observed in 2024. This reflects the mounting global emphasis on sustainability, climate policy, and ecological innovation in response to mounting environmental crises and policy frameworks such as the Paris Agreement, the European Green Deal, and the United Nations Sustainable Development Goals time [76–82].

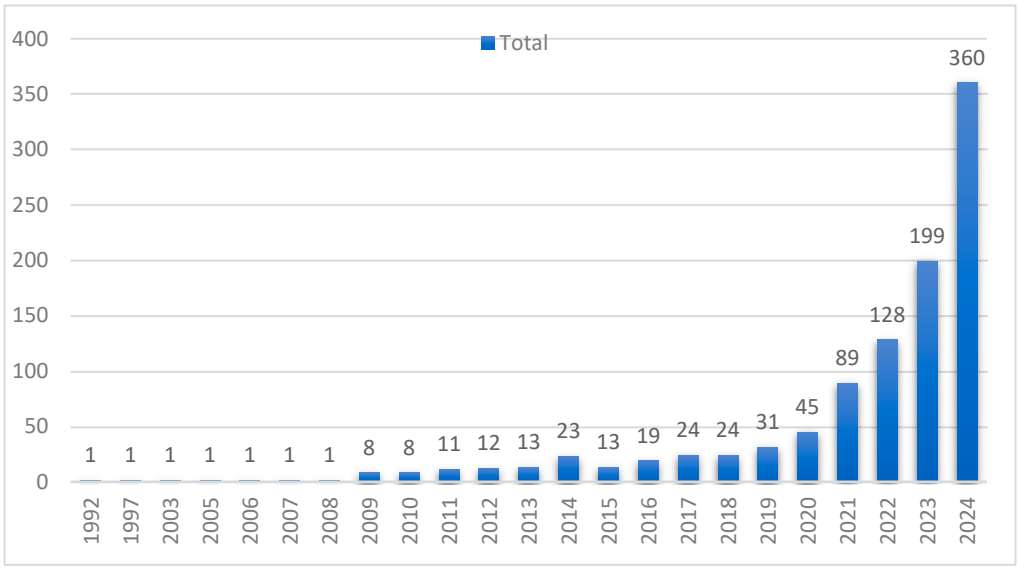


Figure 2. Annual distribution of publications in the green economy and sustainability transition literature, showing a clear upward trend over the past decade, reflecting growing scholarly interest and the increasing relevance of sustainability research globally.

The early 1990s to early 2000s saw limited scholarly contributions on these topics, likely due to the nascent stage of global environmental governance and a fragmented understanding of sustainability transitions. However, from around 2019, there has been a rapid expansion in the volume of academic work, coinciding with greater institutional alignment, increased funding for green research, and heightened public awareness of climate change and socio-ecological challenges.

This temporal trend underscores not only the growing scholarly interest but also the increasing policy relevance of research in this domain. It suggests that the green economy and sustainable development have become entrenched themes across multiple disciplines, including economics, environmental science, and policy studies.

The rising publication trend affirms the timeliness of this study and validates the use of bibliometric methods to uncover patterns, co-authorship dynamics, and intellectual structures in this evolving body of research.

4.2. Bibliometric Analysis

4.2.1. Co-Authorship by Authors Analysis

The co-authorship network map presented in Figure 3 offers valuable insights into the collaborative structure of the research field concerning the green economy, green transition, and sustainable development. A total of 28 authors met the threshold for minimum number of publications and co-authorship links and were consequently visualized in the map. These authors were organized into two distinct clusters, suggesting differentiated patterns of collaboration and possibly distinct research sub-communities within the broader field.

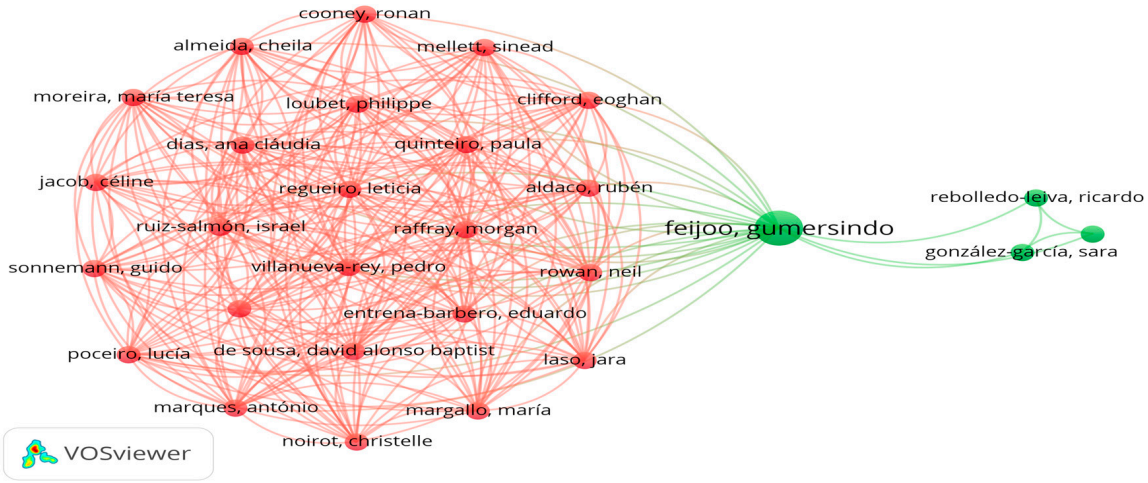


Figure 3. Co-authorship network of authors in green economy research, indicating central contributors with the strongest collaborative ties, and highlighting key hubs in global research collaboration.

Cluster 1 (Red Cluster): This is the larger and more densely interconnected group, comprising 24 authors. The dense network of red lines illustrates a high degree of collaboration among scholars such as Ronan Cooney, Cheila Almeida, Philippe Loubet, Ana Cláudia Dias, and Leticia Regueiro. The close proximity of nodes and extensive linkages within this cluster suggest a cohesive scholarly community with frequent joint publications. Many of these researchers are affiliated with European institutions, reflecting the dominant role of Europe in sustainability research. The intensity of collaboration may also be linked to multi-institutional initiatives and EU-funded research programs such as Horizon 2020, which actively promote cross-border partnerships and networks.

Cluster 2 (Green Cluster): This smaller cluster includes four authors: Gumersindo Feijoo, Sara González-García, Ricardo Rebolledo-Leiva, and one additional co-author. The links between these authors are exclusively internal, forming a tightly knit but relatively isolated sub-network. Notably, Gumersindo Feijoo functions as a key node or bridging figure, maintaining co-authorship links not only within Cluster 2 but also with select individuals in Cluster 1. This bridging role suggests that Feijoo may serve as a collaborative conduit between otherwise disjointed research groups, thereby fostering interdisciplinary and inter-institutional partnerships. The smaller size and relative isolation of this cluster may indicate specialization in a narrower research niche, likely tied to life-cycle analysis and environmental assessment studies where these authors have been particularly active.

The visualization of these clusters is not merely structural but also reflects functional segmentation in scholarly activity. Cluster 1 appears to represent a larger, more generalist research community with strong European institutional backing, while Cluster 2 indicates a specialized and regionally concentrated research effort. This differentiation suggests that while international collaborations dominate the broader landscape, there remain opportu-

nities to integrate smaller, specialized clusters into larger, global research networks. The strength of the co-authorship ties, depicted by the thickness of the connecting lines, further reinforces these patterns. For instance, the strong links between Feijoo, González-García, and Rebolledo-Leiva denote recurring collaborative output across multiple publications and projects, underscoring the role of smaller but tightly integrated research teams in advancing niche areas.

4.2.2. Co-Authorship by Country Analysis

Based on the co-authorship network visualization (see Figure 3), a co-authorship by country analysis (Figure 4) was performed to uncover the underlying structure and rationale behind international research collaboration in the field. This analysis aims to reveal patterns of global scientific cooperation, identify national research hubs, and understand the geopolitical distribution of academic knowledge production.

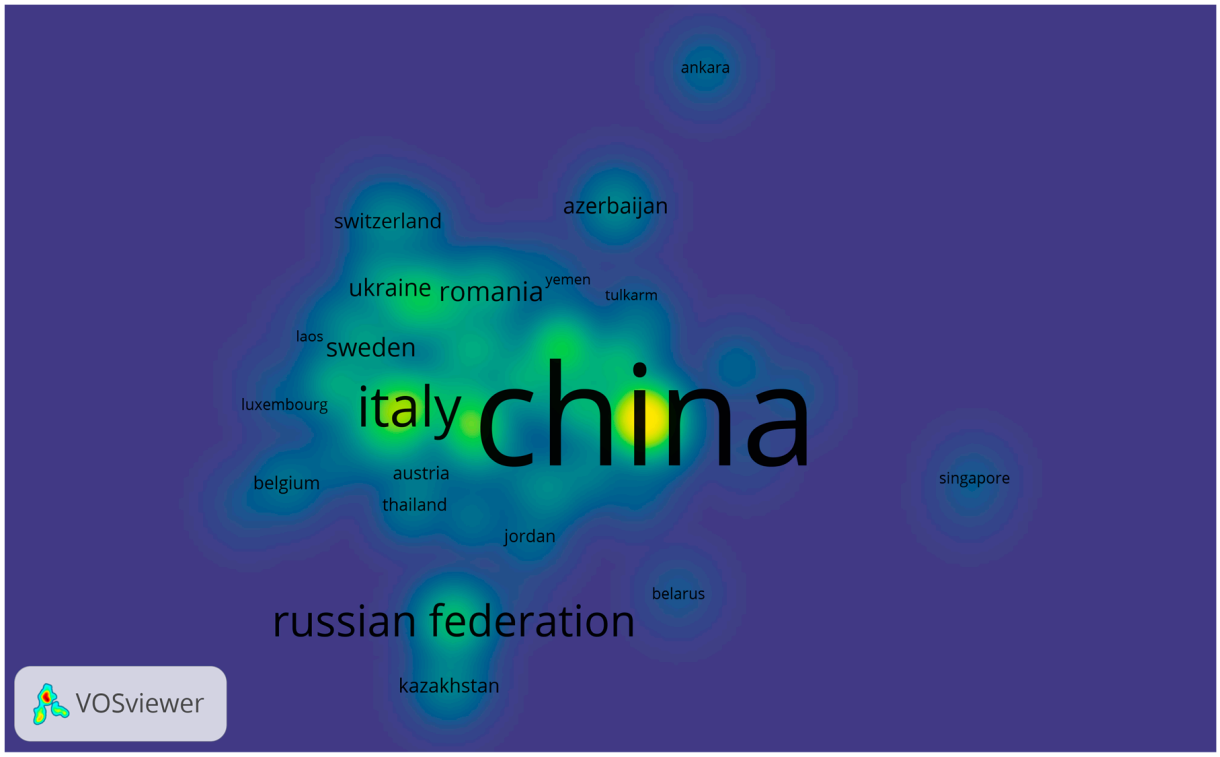


Figure 4. Co-authorship network by country, revealing that research collaboration is concentrated in Europe, North America, and parts of Asia, while regions such as Africa and Latin America remain underrepresented, indicating opportunities to foster more globally inclusive research networks.

The bibliometric data revealed a total of 109 countries actively contributing to the literature, which were systematically grouped into 13 distinct clusters. Each cluster contained between 4 and 13 countries, indicating varying degrees of interconnectedness and thematic alignment. These clusters were generated using VOSviewer's clustering algorithm, which detects communities based on the strength of co-authorship linkages, allowing for the identification of functional segmentation in global research efforts. The number of co-authors from each country was recorded, with China leading with 600 co-authors, followed by Italy (269), the Russian Federation (172), and Romania (72). Table 1 presents the number of co-authors from each country.

Table 1. Co-authors per country.

Country	Number of Co-Authors	Country	Number of Co-Authors	Country	Number of Co-Authors
China	600	Italy	269	Russian Federation	172
United Kingdom	141	India	139	Spain	104
United States	102	Germany	89	Brazil	72
Romania	72	Ukraine	73	Pakistan	69
Poland	59	Turkey	56	Australia	53
Kazakhstan	50	Vietnam	50	Sweden	47
Indonesia	44	France	43	South Africa	42
Norway	39	The Netherlands	36	Malaysia	36
Saudi Arabia	32	Hungary	31	Switzerland	29
Denmark	28	Greece	27	Finland	26
Japan	25	Canada	24	South Korea	24
Portugal	23	Nigeria	22	Taiwan	22
Tunisia	22	Ireland	20	Latvia	19
Serbia	18	Croatia	17	Lithuania	16
Azerbaijan	16	Hong Kong	14	Austria	14
Mexico	14	Belgium	13	Kyrgyzstan	11
Ghana	13	Argentina	11	Bangladesh	11
Uzbekistan	11	Slovenia	10	Morocco	10
Bulgaria	10	Slovakia	9	Thailand	9
Iran	9	Ethiopia	7	Czech Republic	6
Jordan	8	Peru	7	Belarus	5
Estonia	8	United Arab Emirates	7	Bahrain	5
Cyprus	8	Chile	6	Philippines	5
North Macedonia	8	Lebanon	6	Qatar	5
Bosnia and Herzegovina	4	Central African Republic	3	New Zealand	3
Montenegro	4	India	3	Iceland	3
Togo	4	Cuba	3	Luxembourg	3
Sakarya	3	Armenia	3	Myanmar	3
Namibia	3	Kenya	1	Serdiva	1
Laos	2	Costa Rica	1	Tanzania	1
Iraq	2	Sweden	1	Botswana	1
Colombia	2	Zambia	1	Kuwait	1
Trinidad and Tobago	2	Poland	1	Damascus	1
Singapore	2	Pakistan	1	Oman	1
Egypt	2	Sri Lanka	1	Yemen	1

Table 1. *Cont.*

Country	Number of Co-Authors	Country	Number of Co-Authors	Country	Number of Co-Authors
Georgia	2	Tulkarm	1	Brunei Darus-salam	1
Ecuador		Tajikistan		Maldives	1
Ankara	1	Madagascar	1	Djibouti	1
Benin	1	-	-	-	-

The co-authorship map displays country names with font size proportional to the number of publications and link strength, while color density reflects collaboration intensity. China emerged as the most prominent node in the network, indicating its dominant role as a central contributor to global scholarship in the field. This dominance can be attributed to strong national research funding, strategic policy focus on sustainability, and coordinated institutional networks. Italy, the Russian Federation, and Romania also demonstrated high collaboration activity, reflecting established research traditions and active participation in international research initiatives.

The visualization highlights several key observations:

- Cluster centralization around China suggests that it not only leads in publication volume but also plays a pivotal role in fostering transnational collaborations, especially with countries across Asia, Europe, and parts of the Middle East, likely supported by targeted research funding and bilateral partnerships.
- European countries such as Italy, Switzerland, Ukraine, Sweden, and Belgium exhibit high levels of interconnectedness, forming dense collaborative clusters, likely facilitated by EU research frameworks, funding mechanisms, and historical academic ties.
- Countries like Singapore, Azerbaijan, and Thailand, although less central, appear as part of the global network, indicating emerging contributions or niche research collaborations, possibly driven by specialized environmental research programs.
- The presence of countries such as Kazakhstan, Laos, Jordan, and Yemen in the map, albeit with weaker connections, underscores the expanding geographic footprint of sustainability and innovation-related research, even in traditionally underrepresented regions. These links may reflect growing international partnerships and capacity-building initiatives.

Overall, this analysis demonstrates a highly globalized research landscape, where collaboration networks are influenced not only by geographic proximity but also by national research priorities, institutional alliances, and thematic focus areas such as climate action, circular economy, and green innovation. The functional segmentation observed highlights both regional academic strengths and the influence of international policy frameworks in shaping collaborative patterns.

4.2.3. Keyword Co-Occurrence Analysis

To gain deeper insight into the intellectual structure, thematic landscape, and research trends within the field, a keyword co-occurrence analysis was conducted. This technique examines the frequency and co-occurrence of keywords assigned to documents, enabling the identification of core topics, emerging themes, and conceptual relationships.

The analysis produced 492 distinct keywords (items), which were automatically grouped into nine clusters using the software's clustering algorithm. These clusters represent sets of keywords that frequently appear together across multiple documents, thereby reflecting shared thematic or conceptual domains. Cluster sizes varied substantially, rang-

ing from 18 to 137 items, suggesting different levels of thematic density and scholarly focus (see Figure 5). Each cluster corresponds to a coherent thematic domain and provides interpretive insights into the structure of research in this field:

- Cluster 1 emphasizes *sustainable development and economic growth*, reflecting strong scholarly attention to integrating sustainability into macroeconomic policies and development strategies. The prominence of this cluster underscores the consensus that long-term growth must be reconciled with environmental and social goals.
- Cluster 2 focuses on the *circular economy and recycling*, demonstrating the field's shift toward resource efficiency and regenerative systems. The emphasis on waste minimization and industrial circularity highlights how scholars are exploring practical pathways to sustainability.
- Cluster 3 captures research on *alternative energy and energy policy*. The concentration on renewables and energy transitions reveals how technological innovation and supportive policy frameworks are seen as critical enablers of a sustainable energy future.
- Cluster 4 links *economic development* with *greenhouse gas emissions*, reflecting debates around decoupling growth from carbon intensity. This cluster highlights the tension between industrialization and climate goals, particularly in emerging economies.
- Cluster 5 introduces a novel intersection of *natural resources and fintech*. Here, research explores how digital finance, blockchain, and green investment platforms can improve resource governance and accountability, signaling an emerging frontier in the literature.
- Cluster 6 addresses the *green economy and technological innovation*. Thematically, it points to innovation-driven pathways for sustainable transformation, including new industries, employment, and environmental protection.
- Cluster 7 emphasizes *energy use and the green transition*. This cluster underscores issues of energy efficiency, infrastructure, and behavioral change, highlighting the socioeconomic dimensions of energy transitions.
- Cluster 8 is centered on *uncertainty*, drawing attention to risk, resilience, and decision-making under unpredictable environmental and market conditions. This reflects an important conceptual concern with how institutions manage volatility in sustainability planning.
- Cluster 9 concentrates on *carbon reduction*, signaling the policy-oriented nature of much current research. Studies in this cluster focus on carbon trading, corporate disclosure, and net-zero strategies, underscoring the increasing institutionalization of carbon governance.

The co-occurrence map (Figure 5) visually complements these findings by depicting both the relative importance of keywords (node size) and the strength of their conceptual connections (link thickness). Keywords positioned closely together denote strong thematic linkages, while isolated terms point to niche or emerging areas of inquiry.

Overall, the keyword co-occurrence analysis demonstrates that the field is not merely descriptive but dynamically structured around interconnected themes. Established domains such as sustainable development and energy transitions are complemented by newer areas like fintech-driven sustainability and uncertainty management. This reveals an evolving intellectual landscape where sustainability, technology, and governance are increasingly studied in relation to one another, offering a more holistic and future-oriented understanding of sustainable development.

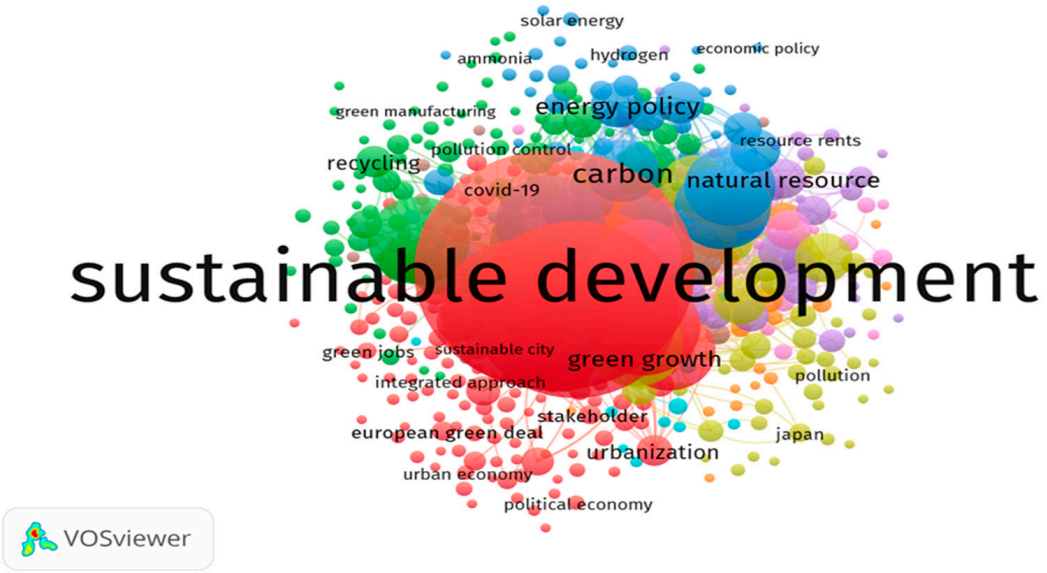


Figure 5. Keyword co-occurrence network in sustainability research, showing nine major thematic clusters including sustainable development, circular economy, green innovation, and renewable energy, which reflect the field's diversification and emerging trends such as fintech and digital transitions.

4.2.4. Citation Analysis

The citation analysis highlights the most influential authors in the field of green economy and sustainability transitions. A total of 11 authors met the inclusion criterion of having at least four publications, enabling the extraction of meaningful bibliometric patterns. These authors were ranked based on their number of citations and total link strength, offering insights into both their academic influence and collaborative relevance within the field (Table 2).

Table 2. Citation by authors.

Author	Documents	Citations	Total Link Strength	Rank
Mahmood, Haider	4	497	1	1
Iraldo, Fabio	4	311	0	2
Ahmed, Zahoor	4	272	1	3
Morone, Piergiuseppe	4	233	1	4
Murshed, Muntasir	4	210	1	5
Passaro, Renato	6	210	1	6
Gyamfi, Bright Akwasi	5	209	2	7
Shahbaz, Muhammad	4	205	0	8
Bashir, Muhammad Farhan	4	114	0	9
Sharif, Arshian	4	99	0	10
Wang, Ying	4	78	0	11

Among the top contributors, Mahmood Haider stands out with 497 citations, reflecting a strong academic footprint despite having only four publications. This suggests that his work on sustainable economic growth and transition strategies is highly impactful and widely referenced. Gyamfi Bright Akwasi follows with five publications and 209 citations, demonstrating the highest total link strength (2) among the authors, indicative of both steady output and strong collaborative networks—traits aligned with policy-driven environmental economics. Other highly cited authors, including Fabio Iraldo (311 citations), Zahoor Ahmed (272 citations), and Piergiuseppe Morone (233 citations), contribute research spanning green innovation adoption, circular economy governance, and industrial

sustainability, all critical to ongoing sustainability transitions. Authors such as Arshian Sharif and Ying Wang, while having lower citation counts and link strengths, contribute to the diversity and breadth of the collaborative network.

These patterns provide insights into what drives cluster formation—notably, the intersection of research productivity, citation impact, and collaborative ties. Linking these findings to initiatives like the European Green Deal and COP28 highlights how leading research informs global policy agendas and underlines the practical relevance of thematic clusters. This enhanced interpretation clarifies implications for future research, emphasizing areas where collaboration and high-impact studies can guide policy development, sustainability transition strategies, and knowledge diffusion.

4.2.5. Source Title Analysis

The bibliographic coupling by sources analysis, conducted to identify the most influential academic journals based on shared references among their publications, revealed a total of 29 source titles. These sources were grouped into four distinct clusters, each representing a cohesive thematic or disciplinary domain within the broader literature on sustainability transitions and green economy. The clusters were identified based on the strength of bibliographic coupling, i.e., the degree to which different journals cite the same references, signaling intellectual proximity and shared topical focus.

Cluster 1 emerged as the largest group, comprising 13 source titles (such as Sustainability; Journal of Cleaner Production; International Journal of Energy Economics and Policy; Resources, Conservation and Recycling; Land; Ecological Economics, etc.). This cluster likely represents journals with a strong focus on environmental sustainability, green innovation, and energy economics, indicating a dense and interconnected scholarly dialogue in this domain.

Cluster 2 contained 10 sources, primarily reflecting journals centered on policy-oriented discussions and circular economy frameworks, where literature convergence is driven by common regulatory and developmental themes (Energy Policy; Environmental Science and Pollution Research; Resources Policy; Energy Policy and Climate Protection, etc.)

Cluster 3 was composed of 5 items, suggesting a niche yet tightly coupled group of journals emphasizing technological innovation, industrial sustainability, and environmental management practices (Journal of Environmental Management; Business Strategy and the Environment; Technological Forecasting and Social Change, etc.).

Finally, Cluster 4, which consisted of only a single source, represents an outlier or a highly specialized journal that, despite limited connections with other sources, holds significance due to its distinct referencing pattern or unique thematic alignment (Reliability: Theory and Applications).

Overall, the bibliographic coupling map (see Figure 6) illustrates the intellectual structure of the field and the interdisciplinary nature of green economy research, as reflected in the citation behavior of authors across diverse but related journals. The varying cluster sizes also suggest differences in journal prominence, specialization, and thematic coherence within the bibliometric landscape.

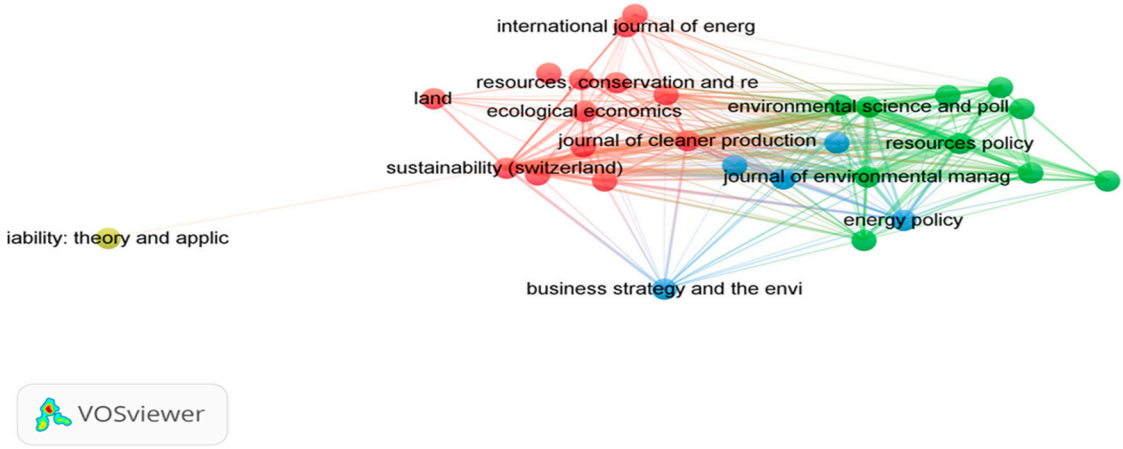


Figure 6. Analysis of publication sources, highlighting the most frequently used journals in green economy and sustainability transition research, which can guide researchers in targeting high impact outlets for dissemination and collaboration.

5. Discussion and Contributions

The findings from the bibliometric analysis provide a comprehensive understanding of the intellectual structure, collaboration dynamics, and thematic progression within the evolving field of green economy and sustainability transitions. As the global community intensifies its focus on achieving environmental sustainability and inclusive economic development [83], scholarly interest in these domains has expanded considerably over the past decade. This growing body of literature reflects the complexity and interconnectedness of sustainable development challenges, with research increasingly spanning diverse areas such as renewable energy, circular economy, green innovation, carbon reduction, and policy reform. Similar trends have been reported in [84,85], which also emphasize the surge of interdisciplinary research addressing sustainability transitions.

The keyword co-occurrence analysis revealed nine distinct thematic clusters that capture the breadth of scholarly engagement with the subject. Central themes such as sustainable development, economic growth, energy policy, and green technological innovation feature prominently, while emerging concerns like uncertainty, fintech applications, and carbon emission mitigation are gaining traction. This implies a multidisciplinary knowledge base that integrates economics, environmental science, public policy, and technological studies. The cluster focusing on circular economy and recycling, for instance, highlights the operational shift from linear to regenerative production systems [86], while the green energy transition cluster points to the centrality of clean energy in long-term sustainability goals [87]. Comparable findings are seen in [88], who stress the importance of circular economy adoption, and [89], who highlights the centrality of clean energy for achieving sustainability milestones.

In contrast, recent bibliometric reviews highlight a stronger focus on digitalization and Industry 4.0 technologies as emerging enablers of sustainability, particularly within manufacturing and energy transition contexts [90–92]. While our analysis identifies circular economy and clean energy as central clusters, these studies demonstrate how AI, big data, and blockchain are increasingly woven into sustainability discourses. Furthermore, whereas our results, similar to those of [93,94], point to fragmented collaboration across regions, other studies such as [95–97] report stronger cross-regional linkages in renewable-energy subfields. This indicates that certain domains, particularly renewable energy, may be consolidating more rapidly than the broader sustainability-transition literature.

Parallel to the thematic expansion is a noticeable upward trajectory in publication output, as demonstrated by the descriptive analysis. This suggests a strong and increas-

ing academic response to global sustainability imperatives, especially in the wake of mounting climate-related risks and the institutionalization of the Sustainable Development Goals [98]. This finding implies a growing recognition of the need for systemic transformations across sectors [99], further reinforcing the relevance of this body of knowledge to both academia and policymaking. The results align with prior critical review and analyses, such as those by [100], which also document rising research output linked to climate action and the SDGs.

Co-authorship analyses revealed nuanced insights into collaborative patterns. The analysis at the author level showed a relatively concentrated network, with a few prolific contributors and many authors with limited co-authorship linkages. At the country level, the collaboration map revealed broader but uneven international engagement, with several clusters indicating regional partnerships, especially among scholars from China, the United States, and parts of Europe. While some countries exhibited dense collaborative ties, the presence of numerous small or isolated nodes points to the fragmentation in global research cooperation. These results underscore both the opportunity and necessity for enhancing academic collaboration, particularly involving underrepresented regions such as Africa [101], so as to enrich the field with diverse contextual insights and foster more inclusive knowledge production. Comparable patterns of concentrated collaboration in advanced economies and weaker participation from the Global South have also been noted in sustainability-related bibliometric studies by [102,103].

Citation analysis offered another layer of depth, identifying the most influential scholars shaping the discourse. Authors such as Mahmood, Haider and Gyamfi, and Bright Akwasi stood out for their high citation impact despite relatively modest publication counts. This suggests that their work resonates strongly within the academic community, potentially serving as theoretical or methodological cornerstones for subsequent research. The citation network also revealed a limited degree of co-citation clustering, pointing again to a field where impactful work exists but is not yet fully integrated into a cohesive intellectual core. This fragmentation highlights an ongoing need for consolidation, theoretical convergence, and dialogue across research strands [104]. Comparable fragmentation has been observed in energy transition research by [105], further indicating that while influential contributions exist, theoretical integration is still developing across sustainability domains.

Furthermore, the bibliographic coupling analysis of source titles demonstrated that knowledge production is being disseminated across a mix of well-established and emerging academic journals. The coupling patterns revealed four main clusters of journals, indicating both consolidation around certain core outlets and the gradual diffusion of relevant work across diverse publication platforms. This reflects the interdisciplinary nature of the field and supports the argument that sustainability transitions demand insights from multiple domains, including economics, environmental policy, energy studies, and innovation management [106]. A similar diffusion pattern is reported in bibliometric reviews by [107], which also document the growing interdisciplinarity of sustainability scholarship.

Taken together, these findings make several important contributions to the existing literature. First, they provide a systematic mapping of the field's intellectual foundations, highlighting key research themes, influential authors, and dominant publication venues. Second, they identify areas of fragmentation in scholarly collaboration and citation practices, offering direction for building more connected academic communities. Third, the identification of thematic gaps, such as limited integration of fintech in green transitions or the relatively recent attention to uncertainty in sustainability planning points to emerging frontiers that warrant deeper investigation. Fourth, the results underscore the alignment of academic research with global policy discourses, particularly regarding climate action, responsible consumption, and inclusive economic growth, suggesting strong potential for

research to inform evidence-based policymaking. Finally, by employing a multi-layered bibliometric methodology, this study demonstrates a replicable framework for analyzing other complex and interdisciplinary research fields.

In essence, the study sheds light on the current state and future direction of research on green economy and sustainability transitions. It contributes to both academic understanding and practical discourse by identifying intellectual anchors, mapping the evolution of core themes, and revealing collaboration patterns that shape the future of sustainability scholarship.

6. Conclusions and Implications

This study employed a bibliometric analysis to investigate the intellectual landscape, collaboration patterns, and thematic evolution of research on the green economy and sustainability transitions. Drawing upon a dataset of high-impact publications, the analysis revealed a dynamic and rapidly expanding field characterized by growing scholarly interest, interdisciplinary integration, and increasingly diverse methodological and conceptual approaches. The upward trend in publications over the past decade underscores the urgency and global relevance of sustainability transitions, especially in light of escalating climate change impacts, resource depletion, and the need for inclusive economic models.

The co-authorship and citation analyses pointed to a field that, while rich in influential contributions, remains somewhat fragmented in terms of collaboration and knowledge consolidation. The limited but growing networks of scholarly collaboration, particularly at the country level, show a significant opportunity for strengthening partnerships, especially with institutions and researchers in underrepresented regions such as Africa, Latin America and parts of Asia. Fostering more equitable global research collaborations will be critical for contextualizing sustainability solutions and addressing region-specific development challenges.

Thematic analysis through keyword co-occurrence identified nine major research clusters, indicating a healthy diversification of focus areas including sustainable development, circular economy, alternative energy, green innovation, and carbon reduction. The emergence of newer themes such as fintech, policy uncertainty, and digital transitions reflects the field's responsiveness to global technological and socioeconomic shifts. However, the limited integration of these emerging themes with mainstream sustainability debates signals the need for more integrative frameworks that can capture the complex interdependencies between technology, finance, and environmental governance.

From a policy perspective, these findings provide several concrete directions. For instance, governments and funding agencies could leverage the identified research clusters to prioritize strategic investments, such as channeling resources into renewable energy innovation or circular economy initiatives where research momentum is already strong. The recognition of emerging clusters such as fintech and digital transitions also suggests that policymakers could design cross-sectoral programs that integrate digital technologies with sustainability efforts. Furthermore, the uneven regional collaboration patterns highlight the importance of international partnerships that actively incorporate underrepresented regions, including Africa and parts of Latin America, into global sustainability research networks. Targeted funding for South–South and North–South collaborations, along with capacity-building initiatives, would not only diversify knowledge production but also enhance the global applicability of sustainability research outcomes.

From a theoretical standpoint, this study contributes to the systematization of knowledge in the green economy and sustainability transition literature. It offers a consolidated view of the core research streams and highlights underexplored areas that warrant deeper inquiry, such as the role of financial technology, behavioral uncertainty, and cross-sectoral

policy alignment. Furthermore, the results support the continued relevance of foundational theories such as ecological modernization, innovation systems, and institutional change, while also pointing toward the need for novel conceptual tools capable of addressing twenty-first-century sustainability challenges.

In comparison to earlier bibliometric works, this study provides three distinctive contributions. First, it integrates emerging yet underexplored dimensions such as fintech applications, digital transitions, and policy uncertainty into the sustainability discourse, highlighting new frontiers for research. Second, it emphasizes the geographical imbalances in scholarly collaboration by shedding light on the underrepresentation of Africa, Latin America, and parts of Asia—an angle less visible in prior reviews. Third, it links bibliometric patterns explicitly to practical and policy implications, offering actionable insights for policymakers, funding institutions, and scholars on how to close thematic and regional gaps.

The analysis reveals a dynamic and rapidly expanding field, characterized by interdisciplinary integration, methodological diversity, and growing scholarly interest. The identified research clusters offer actionable insights for governments, research funders, and academic institutions. Policymakers can leverage these clusters to design evidence-based, inclusive, and context-sensitive sustainability policies that align with global initiatives such as the European Green Deal and COP28. Funding agencies and academic institutions can use these insights to strategically allocate resources, support emerging areas such as fintech, digital transitions, and policy uncertainty, and foster interdisciplinary collaborations that bridge thematic gaps. Prioritizing investment in high-impact clusters can accelerate the development of innovative and practical sustainability solutions.

The co-authorship and citation analyses depict geographic imbalances in scholarly collaboration. Regions such as Africa, Latin America, and parts of Asia remain underrepresented in global research networks. Strengthening partnerships with these regions can enhance the contextual relevance of sustainability research, support capacity building, and foster equitable knowledge exchange. Encouraging South-South and East–West collaborations, as well as mentoring early-career scholars in emerging regions, can expand participation and inclusivity, ensuring that research outputs reflect diverse perspectives and local needs.

The study provides a roadmap for researchers by identifying high-impact authors, thematic gaps, and key journals. This facilitates targeted collaboration, guides publication strategies, and highlights underexplored areas requiring further inquiry. Integrating emerging topics such as green fintech, digital transformation, and cross-sectoral policy alignment into mainstream sustainability research can advance theory development and strengthen the evidence base for policy interventions.

In conclusion, the green economy and sustainability transition literature is maturing into a critical field with both academic and societal relevance. By linking bibliometric insights to practical, policy, and equity considerations, this study underscores the importance of inclusive, globally coordinated research efforts to address complex ecological, economic, and social challenges.

7. Limitations and Future Research Agenda

While this study provides valuable insights into the structure and evolution of research on green economy and sustainability transitions, several limitations must be acknowledged. First, the analysis was based solely on publications indexed in the Scopus database. Although Scopus is one of the most comprehensive and widely used bibliometric sources, it does not capture the full breadth of scholarly work available in other databases such as Web of Science or Google Scholar. As a result, potentially influential

studies, particularly those from emerging journals or grey literature, may have been omitted. Future research should consider multi-database integration to ensure a more holistic coverage of the literature and to minimize selection bias.

Second, the study was limited to English-language publications, which may have excluded important contributions published in other languages. This language restriction can lead to a Western-centric perspective and overlook regionally grounded knowledge, especially from non-Anglophone countries in Latin America, Asia, and Africa. Future bibliometric and content analyses should strive to incorporate multilingual corpora to capture a more diverse range of theoretical and empirical insights.

Third, the reliance on bibliometric indicators, such as citation counts, co-authorship networks, and keyword co-occurrences, while offering objectivity and reproducibility, inherently limits the depth of qualitative understanding. Such methods often overlook the context, methodological rigor, and practical implications of the cited works. Additionally, co-occurrence-based keyword clustering may fail to capture semantic nuances, synonyms, or evolving terminology within the field. To address this, future studies should combine bibliometric analysis with systematic reviews, content analysis, or meta-synthesis techniques, which can uncover conceptual developments, theoretical contributions, and narrative shifts over time.

Moreover, future research could leverage natural language processing and machine learning tools to conduct semantic topic modeling, which allows for more precise interpretation of textual data beyond keyword frequency. This would enhance the capacity to detect emerging themes, interdisciplinary overlaps, and deeper conceptual linkages.

In summary, addressing these limitations will require a more inclusive, multilingual, and methodologically plural approach to knowledge mapping. By combining quantitative bibliometric techniques with qualitative synthesis and leveraging computational advances, future research can provide a richer and more balanced understanding of the green economy and sustainability transition discourse.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/world6040140/s1, including PRISMA 2020 Checklist [75]: Reporting checklist for systematic review, completed in accordance with the PRISMA guidelines.

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Abbreviations

The following abbreviations are used in this manuscript:

OECD	Organisation for Economic Cooperation and Development
SDGs	Sustainable Development Goals

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