GREEN INVESTMENTS, ENERGY TRANSITION, AND FINANCIAL MARKETS: A BIBLIOMETRIC REVIEW OF THE 2021–2025 LITERATURE

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Abstract

The accelerating expansion of green investment and climate-oriented finance has intensified scholarly interest in the relationship between financial markets and the energy transition. However, as this literature has evolved across partially overlapping streams, there is a clear need to map its recent intellectual structure, thematic concentrations, and bridging areas. This study provides a comprehensive bibliometric review of research indexed in the Web of Science Core Collection, focusing specifically on the intersection of green investments, the energy transition, and financial markets. The analysis covers the period 2021–2025, with the dataset finalized on April 1, 2026. After applying temporal filters and restricting the sample to original research and review articles, a final corpus of 154 documents was established. Bibliometric mapping was performed using VOSviewer (v1.6.20) through co-occurrence analysis of all keywords. Using a minimum occurrence threshold of six and a thesaurus-based normalization procedure, the resulting network identified 27 key terms organized into three distinct thematic clusters. This was further complemented by a TIE/bridges analysis to identify cross-cluster documents. The results reveal that the field is structured around three core domains: green finance and sustainability-oriented transitions; financial market risk and transmission mechanisms; and climate finance, renewable energy, and return dynamics. The bridge analysis demonstrates that the strongest thematic interfaces emerge between market-risk studies and renewable energy finance, as well as between transition-oriented green finance and investment performance debates. By clarifying the recent structure of this rapidly expanding literature, this study identifies existing tensions, highlights policy relevance, and proposes critical directions for future research.

Keywords: *green finance; green investment; energy transition; financial markets; climate finance; renewable energy; bibliometric analysis*

JEL Classification: *G11; G12; G14; Q42; Q56*

1. Introduction and context of the study

The transition toward a lower-carbon economy has turned green investment and climate-oriented finance into central topics in contemporary economic research. As decarbonization pressures intensify, financial systems are increasingly expected to mobilize capital toward renewable energy, clean technologies, and sustainability-oriented innovation. In this context, green finance is no longer discussed only as an environmental policy complement, but also as a mechanism of capital allocation, market signaling, and strategic risk management. Recent studies show that the relationship between finance and the energy transition is not one-directional: financial innovation can accelerate transition processes, while transition dynamics can also reshape financial instruments, market expectations, and portfolio strategies (Luo et al., 2022; Tiwari et al., 2024; Ziolo et al., 2025).

These broad systemic shifts are reflected in the strategic reorientation of traditional energy firms, which are increasingly turning to digitalization and service diversification to stay resilient amid global economic and environmental volatility (Panduru & Scarlat, 2022). In the Romanian context, such adaptations within fuel retail networks demonstrate how global sustainability trends are being translated into practical, technology-driven operational changes at the corporate level As these streams have expanded, the field has become richer but also more fragmented.

At the same time, the literature has become increasingly differentiated. One stream examines the macro and meso role of green finance in supporting sustainable development, innovation, and climate commitments (Luo et al., 2022; Dunbar & Treku, 2025). Another focuses on financial-market mechanisms, especially volatility, spillovers, connectedness, carbon pricing, uncertainty, and the pricing of transition-related risks (Bouri et al., 2022; Wu et al., 2024; Wu & Qin, 2024). A third stream pays closer attention to renewable energy, climate finance, oil-price dynamics, risk exposure, and the return profile of green assets and funds (Care & Weber, 2023; Ftiti et al., 2025; Wang, 2024). As these streams have expanded, the field has become richer, but also more fragmented.

This fragmentation creates a clear bibliometric need. Although prior contributions discuss sustainable finance, climate finance, green bonds, renewable energy investment, or transition-related market risks, the recent literature located specifically at the intersection of green

investments, energy transition, and financial markets has not been sufficiently mapped as an integrated research domain. Existing work often privileges one of these dimensions while treating the others as contextual variables. As a result, we still lack a focused overview of the recent intellectual structure of this combined field, the thematic clusters that organize it, and the bridge zones through which ideas circulate between sustainability-oriented finance, market-based risk analysis, and renewable-energy investment debates (Luo et al., 2022; Care & Weber, 2023; Ziolo et al., 2025; Todorova et al., 2025).

The importance of such mapping is amplified by the rapid evolution of the post-2020 literature. In the last few years, the field has been shaped by stronger climate-policy commitments, growing investor attention to ESG and green assets, persistent uncertainty in energy markets, and renewed interest in transition-related risks and opportunities. Research increasingly addresses not only whether green finance supports decarbonization, but also how financial markets price transition signals, how uncertainty affects green and brown assets, and how investors respond to changing energy and policy conditions (Bouri et al., 2022; Wu et al., 2024; Campiglio et al., 2025).
Against this background, the present study aims to provide a recent bibliometric review of the literature on green investments, energy transition, and financial markets indexed in the Web of Science Core Collection during 2021–2025. More specifically, the article seeks to identify the dominant thematic clusters, assess their disciplinary anchoring, trace the temporal dynamics of the field, and examine the cross-cluster interfaces captured through a TIE/bridges procedure.

Accordingly, the study addresses the following research questions:

RQ1. *What is the recent intellectual structure of the literature on green investments, energy transition, and financial markets during 2021–2025?*

RQ2. *What thematic clusters and bridge relations organize the field and explain the connections between green finance, market dynamics, and transition-related investment debates?*

RQ3. *How has the literature evolved over time, and what future research directions emerge from the current thematic configuration?*

The contribution of the article is threefold. First, it offers a focused and up-to-date bibliometric synthesis of a rapidly expanding research domain. Second, it moves beyond simple descriptive mapping by combining keyword-network analysis with disciplinary validation through WoS Categories and Research Areas, together with bridge analysis for multi-cluster documents. Third, it develops an interpretation of the field that remains firmly anchored in economics and finance, emphasizing the interaction among capital allocation, market risk, transition incentives, and sustainability objectives. In this sense, the study responds directly to the need for a more integrated view of how financial markets are implicated in the energy transition and how green investment research is currently being structured.

2. Materials and Methods

2.1. Data source and search strategy

To build the database for this study, we utilized the Web of Science Core Collection as our primary source. The search strategy was intentionally structured to identify research situated at the intersection of three key conceptual pillars: green investments and finance, the energy transition and decarbonization, and financial markets and investors. This led to the formulation of the following topic query:

TS=(("green investment*" OR "green finance" OR "sustainable investment*" OR "climate finance") AND ("energy transition" OR decarbonization OR "low-carbon transition") AND ("financial market*" OR "stock market*" OR "equity market*" OR investor*))

The choice of the Topic (TS) field was motivated by its ability to scan titles, abstracts, author keywords, and Keywords Plus, thereby retrieving a corpus that is both targeted and inclusive. This specific approach ensured that the analysis remained focused on the economic and

financial dimensions of the energy transition, avoiding a shift toward literature that is strictly limited to technical or engineering perspectives.

2.2. Temporal window and filtering procedure

The research focuses on the period from 2021 to 2025 to capture the most recent phase of scholarly activity under consistent, full-year conditions. Data collection was finalized on April 1, 2026, at 18:00 EET (Bucharest). The initial topic search yielded 190 records. By applying the 2021–2025 temporal filter, the dataset was narrowed to 155 documents. A final restriction to only original research and review articles resulted in a corpus of 154 documents, consisting of 145 articles and 9 reviews. This selection process is summarized in Table 1.

Table 1. Dataset selection and filtering procedure

Step	Criteria	Records
Initial search	TS query	190
Temporal filter	2021–2025	155
Document type filter	Article + Review Article	154

Source: Own research

The decision to exclude 2026 from the primary analytical window was a methodological choice rather than a substantive one. Since 2026 was still in progress at the time of the data freeze, its inclusion would have compromised year-over-year comparability and potentially introduced bias into the interpretation of publication trends.

2.3. Bibliometric mapping in VOSviewer

The bibliometric mapping process was carried out using VOSviewer (v. 1.6.20), employing a co-occurrence analysis with "All keywords" as the primary analytical unit and the complete counting method of a map embedded in the bibliographic data (Grigore et al., 2025). During the initial exploratory phase, various minimum-occurrence thresholds were evaluated to optimize the network structure. A threshold of 6 occurrences was ultimately selected because it yielded a more conceptually coherent configuration; in contrast, lower-threshold alternatives tended to produce an additional but fragmented and weakly defined cluster. Under this final specification, the network retained 27 terms organized into three distinct thematic clusters.

This particular configuration was chosen to strike an effective balance between interpretability and comprehensive thematic depth. The resulting network is sufficiently compact to allow for detailed cluster-level analysis while still preserving the core conceptual pillars of the research field. This methodological approach, which prioritizes relevance-based term selection and specific occurrence thresholds, adheres strictly to established VOSviewer workflows for generating readable and analytically robust visualizations. Such techniques are increasingly utilized in recent bibliometric research to map the evolution of technological facilitators and their impact on organizational performance (Barbu et al., 2024).

2.4. Thesaurus normalization

To preserve the semantic integrity of the keyword network, a dedicated thesaurus file was implemented prior to the definitive generation of the bibliometric map. This intervention was instrumental in consolidating various lexical permutation, ranging from singular and plural nuances to hyphenated terms and synonymous expressions, thereby preempting any artificial fragmentation within the network. By aggregating semantically synonymous terms into centralized nodes, the analysis successfully mitigated the risk of diluting the underlying thematic architecture, a critical methodological precaution in a research domain where pivotal terms such as "financial markets," "green investments," and "climate risks" frequently emerge through a multitude of linguistic variations.

2.5. Cluster validation through WoS Categories and Research Areas

The interpretation of thematic clusters extended beyond mere keyword proximity. We validated each cluster by analyzing the dominant Web of Science (WoS) Categories and Research Areas associated with the constituent documents. This procedure verified that the semantic profile of each cluster remained consistent with its disciplinary foundations. In practice, the primary keyword structure of every cluster was triangulated against the top three WoS Categories and Research Areas, then further cross-referenced with representative support papers. This multi-layered approach minimized the risk of overinterpreting isolated keyword groupings and enhanced the overall robustness of the final thematic labels.

2.6. TIE/bridges rule

Beyond standard network mapping, the study implemented a specific scoring procedure to identify "bridge documents" situated between clusters. For every record, a consolidated text field was generated by combining the title, abstract, and both author and Keywords Plus terms. Based on cluster-specific keyword lists, each document was assigned scores for each thematic area, which determined its primary classification. In instances where a document achieved identical maximum scores for two or more clusters, it was designated as a "TIE". This methodology allowed us to move beyond a static view of isolated clusters, instead analyzing the field as a dynamic network of cross-cluster interfaces.

2.7. Scope discipline and interpretive focus

While the search strategy inherently captured interdisciplinary research, the analytical focus of this review remains firmly rooted in the fields of economics, finance, and investment analysis. Consequently, our interpretation of thematic clusters, bridge relations, and temporal trends centers on critical concepts such as capital allocation, financial intermediation, market signaling, and risk management. This perspective aligns with the study's objective to examine the financial dimensions of the energy transition, ensuring that the findings remain relevant to both economic scholarship and policy-driven investment debates.

3. Results

3.1. Overall network structure

The resulting co-occurrence map, which identifies 27 key terms organized into three distinct clusters, demonstrates that the recent literature at the intersection of green investments, the energy transition, and financial markets is defined by a compact yet well-differentiated conceptual architecture (Figure 1). Rather than appearing as a uniform body of research, the field is partitioned into three interconnected thematic areas: a foundational core focused on transition-oriented green finance, a secondary domain exploring financial market risk and transmission mechanisms, and a third segment centered on the performance and investment dynamics of renewable energy and climate finance. This specific configuration indicates that contemporary scholarship is concurrently examining the strategic mobilization of sustainable capital, the market channels through which transition-related shocks propagate, and the financial outcomes linked to renewable energy and climate-oriented assets.

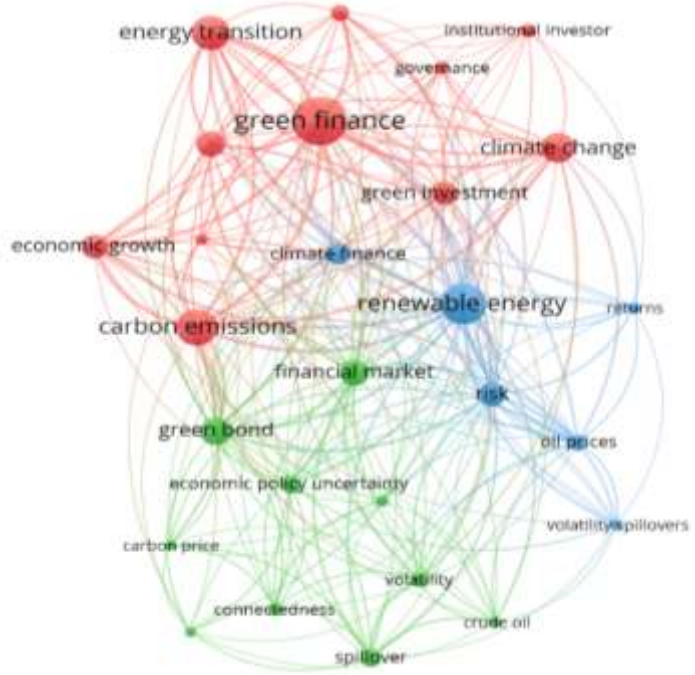

Figure 1. Visualization of the network of the 27 terms across the 3 groups

Source: Authors' own research using VOSviewer

At the document level, the broader corpus also shows a strong asymmetry in thematic concentration. The primary assignment procedure classified 78 documents in C1, 23 in C2, and 19 in C3, while 34 documents were coded as TIE, highlighting a substantial bridge zone across clusters. This distribution indicates that the literature is anchored primarily in the broad nexus between green finance and energy transition, but a considerable share of the field is organized around hybrid articles that connect market risk, policy uncertainty, return dynamics, and renewable-energy finance.

3.2. Temporal dynamics

The temporal analysis of the gathered dataset reveals a significant and sustained expansion of the research field throughout the period under review. Total publication output increased from 8 documents in 2021 to a peak of 58 in 2025, illustrating a robust acceleration in scholarly interest during the latter years of the study. Although 2024 witnessed a brief moderation in output, this minor fluctuation does not deviate from the overarching upward trajectory. On the contrary, the current data suggests that the domain underwent rapid consolidation and achieved its highest level of growth by 2025. These dynamics are detailed in Table 2.

Table 2. Yearly distribution of documents by cluster

An	C1	C2	C3	TIE	Total
2021	2	0	3	3	8
2022	14	4	4	7	29
2023	16	5	4	9	34
2024	10	7	2	6	25
2025	36	7	6	9	58
Total	78	23	19	34	154

Source: Own research

Cluster-specific trends offer a more detailed perspective on this evolution. Cluster 1 (C1) serves as the primary catalyst for the field's expansion, surging from just two publications in 2021

to 36 by 2025. This trajectory confirms that research centered on green finance and sustainability-driven transitions has come to increasingly dominate the scholarly landscape. Meanwhile, Cluster 2 (C2) has maintained a more moderate but steady growth rate, representing a stable research stream focused on market transmission mechanisms, economic uncertainty, and the financial analysis of green bonds. Although Cluster 3 (C3) remains the most specialized and smallest segment, its consistent presence throughout the analyzed period highlights a sustained interest in the intersection of renewable energy, climate finance, and investment return dynamics.

Notably, the TIE segment also expanded over time, rising from three documents in 2021 to nine in 2025, which suggests that cross-cluster integration is becoming more prominent as the literature matures. These temporal results are fundamental to addressing Research Question 3 (RQ3), as they demonstrate a field that is not only scaling in volume but also becoming significantly more interconnected. As publication output increases, a growing number of studies are moving beyond isolated silos to combine previously separate themes, particularly those merging financial market risk with renewable energy investments and climate-aligned capital allocation.

3.3. Cluster-by-cluster analysis

3.3.1. Cluster 1: Green finance, energy transition, and sustainability-oriented transformation

Cluster 1, comprising 11 distinct terms, constitutes the conceptual core of the bibliometric network. The most prominent terms within this cluster include green finance (43 occurrences; TLS = 102), carbon emissions (30; 86), energy transition (28; 66), climate change (23; 61), sustainable development (19; 46), economic growth (18; 60), and green investment (17; 46). As detailed in Table 3, supplementary terms such as innovation, governance, institutional investor, and efficiency further underscore this cluster's role as the most extensive and structurally central domain in the research landscape.

Table 3. Terms in Cluster 1 classified by Occurrences with corresponding TLS

Term	Cluster	Occurrences	Total link strength
green finance	C1	43	102
carbon emissions	C1	30	86
energy transition	C1	28	66
climate change	C1	23	61
sustainable development	C1	19	46
economic growth	C1	18	60
green investment	C1	17	46
innovation	C1	11	36
institutional investor	C1	9	17
governance	C1	8	22
efficiency	C1	7	24

Source: Own research

The semantic architecture of Cluster 1 (C1) reveals that green finance is increasingly positioned as a vital strategic catalyst for the energy transition. The simultaneous presence of keywords such as carbon emissions, climate change, and sustainable development confirms the cluster's deep integration into global sustainability-oriented transformation dialogues. Conversely, the inclusion of terms like economic growth, innovation, and institutional investor highlights a critical emphasis on implementation frameworks and economic scalability. In this context, the development of specialized tool, such as the Business Maturity Framework (BMF), is essential for aligning organizational management and strategy formulation with the demands of sustainable

growth and operational excellence within the oil and gas industry (Panduru et al., 2023). Organizations that are focused on integrating artificial intelligence into their IT asset lifecycle management (ITALM) strategies can achieve their sustainability goals quickly (Crasoveanu et al., 2024). Within this thematic domain, the energy transition is conceptualized not as a mere sectoral shift, but as a comprehensive systemic transformation that demands robust financial support, aligned governance, and enhanced innovation capacity.

This interpretation is further reinforced by disciplinary validation. The primary Web of Science (WoS) Categories associated with C1 include Green & Sustainable Science & Technology (25 articles), Environmental Sciences (24 articles), and Environmental Studies (21 articles). Furthermore, the leading Research Areas identified are Environmental Sciences & Ecology (35 articles), Business & Economics (31 articles), and Science & Technology – Other Topics (25 articles). These distributions, detailed in Table 4, demonstrate that C1 is far from a purely financial grouping; it represents an interdisciplinary, yet economically grounded domain where finance is intricately linked to broader sustainability challenges. The overlap between environmental and business-centric classifications aligns perfectly with the cluster's term profile, cementing its status as the definitive transition-oriented finance cluster in the current literature.

Table 4: The top 3 categories from WoS Categories and Research Areas specific to the articles in Cluster 1

Cluster 1			
WoS Categories		Research Areas	
Category	Article number	Category	Article number
Green & Sustainable Science & Technology	25	Environmental Sciences & Ecology	35
Environmental Sciences	24	Business & Economics	31
Environmental Studies	21	Science & Technology - Other Topics	25

Source: Own research

Luo et al. (2022) show that sustainable finance research has increasingly revolved around climate change, green finance, renewable energy, and governance, providing strong background support for the macro-structural profile observed in C1. Tiwari et al. (2024) directly connect renewable energy, energy innovation, climate change, and green financial development in shaping the energy transition, which mirrors the cluster's coupling of finance, transition, and environmental pressures. Dunbar and Treku (2025) demonstrate that energy-transition investment flows support green-bond issuance and sustainable development objectives, while Ziolo et al. (2025) emphasize the financing role of green bonds and green credits in the transition toward renewable energy sources. Together, these papers confirm that C1 captures the literature that conceptualizes green finance as a central mechanism in the broader transformation toward low-carbon development.

Overall, Cluster 1 answers a major part of RQ1 by showing that the dominant recent stream in the field revolves around the macro and meso foundations of green finance in the energy transition. It also sets the stage for RQ2, since many bridge relations originate from the intersection between this broad transition-oriented domain and the more market-centered clusters.

3.3.2. Cluster 2: Financial market risk, uncertainty, and transmission mechanisms

Cluster 2 includes 10 terms and represents the field's most explicitly market-oriented domain. Its main terms are green bond (21;63), financial market (20;57), spillover (12;34), economic policy uncertainty (12;29), volatility (10;32), connectedness (8;24), climate risk (7;19), carbon price (6;17), crude oil (6;21), and stock market (6;16), as detailed in Table 5. These terms define a cluster centered on the pricing and transmission of shocks across green and traditional financial-energy interfaces. Compared with C1, which emphasizes transition support and sustainability-oriented transformation, C2 focuses much more clearly on market behavior, interdependence, and risk propagation.

Table 5. Terms in Cluster 2 classified by Occurrences with corresponding TLS

Terms	Cluster	Occurrences	Total link strength
green bond	C2	21	63
financial market	C2	20	57
economic policy uncertainty	C2	12	29
spillover	C2	12	34
volatility	C2	10	32
connectedness	C2	8	24
climate risk	C2	7	19
carbon price	C2	6	17
crude oil	C2	6	21
stock market	C2	6	16

Source: Own research

The semantic architecture of Cluster 2 (C2) indicates that the research field has established a robust substream concerned with the complex interactions between green assets, green bonds, traditional energy markets, and the broader financial system, particularly under conditions of uncertainty. The frequent occurrence of terms like spillover, volatility, and connectedness highlights a significant conceptual and methodological emphasis on the dynamic linkages that define modern markets. Simultaneously, the focus on economic policy uncertainty, climate risk, and carbon prices suggests that researchers are increasingly evaluating green finance and transition-related assets through the prism of risk pricing and the transmission of uncertainty.

This strategic shift is mirrored in the traditional energy sector, specifically within the oil and gas industry, where Information and Communication Technology (ICT) and digital transformation drivers, such as energy analytics, the Internet of Things (IoT), and machine learning, have become central to strategic thinking as firms navigate the dual challenge of improving operational efficiency and reducing their environmental footprint (Panduru & Gherman, 2021). Consequently, within this cluster, the energy transition is framed not only as a normative policy goal but as a primary catalyst for market revaluation, systemic shock transmission, and the continuous reclassification of energy-related assets.

The disciplinary architecture of Cluster 2 (C2) demonstrates high congruency with this interpretation, as evidenced by the prevalence of Web of Science (WoS) Categories such as Economics (12), Energy & Fuels (6), and Business, Finance (5), alongside dominant Research Areas including Business & Economics (15), Energy & Fuels (6), and Environmental Sciences & Ecology (5). This thematic composition substantiates that C2 functions at the analytical nexus of economic inquiry, energy-market research, and financial-market modeling; furthermore, in contrast to Cluster 1 (C1), which maintains a deeper integration within sustainability-centric environmental classifications, C2 exhibits a more pronounced orientation toward economic and financial market

mechanisms, as illustrated by the data regarding WoS Categories and Research Areas for C2 presented in Table 6.

Table 6: The top 3 categories from WoS Categories and Research Areas specific to the articles in Cluster 2

Cluster 2			
WoS Categories		Research Areas	
Category	Article number	Category	Article number
Economics	12	Business & Economics	15
Energy & Fuels	6	Energy & Fuels	6
Business, Finance	5	Environmental Sciences & Ecology	5

Source: Own research

Research by Wu et al. (2024) underscores that the interdependence and spillover effects between green finance and conventional energy sectors become more pronounced during periods of extreme market stress, a finding that directly reinforces the cluster's emphasis on "spillover," "connectedness," and "financial market". This focus on dynamic market transmission is further validated by Wu and Qin (2024), who analyze the asymmetric nature of volatility spillovers across ESG, new energy, carbon, and green bond markets.

Additionally, Bouri et al. (2022) highlight how climate policy uncertainty acts as a primary driver for the price movements of both green and brown energy equities, while Sohag et al. (2023) illustrate that green investments are inherently vulnerable to volatility originating from critical mineral markets. Collectively, these works establish Cluster 2 as a domain that interprets the energy transition through the lenses of financial risk, uncertainty, and systemic interdependence.

Consequently, this cluster is instrumental in addressing RQ2 by clarifying the market structures that facilitate the transmission of transition-related signals. Furthermore, its continued relevance suggests that future scholarship (RQ3) will increasingly treat green assets as sophisticated financial instruments subject to diverse forms of both conventional and non-conventional market volatility.

3.3.3. Cluster 3: Climate finance, renewable energy, and return dynamics

Cluster 3 is the smallest of the three keyword clusters, with 6 terms, but it remains conceptually distinct and analytically important. As can be seen in Table 7, the core keywords defining this segment include: renewable energy (35;113), risk (18;58), climate finance (15;35), oil prices (11;43), returns (7;20), and volatility spillovers (7;19) (table 7). Although more compact than the other clusters, C3 captures a specific interface where climate-oriented financing, renewable-energy development, and investment-performance questions converge.

Table 7. Terms in Cluster 3 classified by Occurrences with corresponding TLS

Terms	Cluster	Occurrences	Total link strength
renewable energy	C3	35	113
risk	C3	18	58
climate finance	C3	15	35
oil prices	C3	11	43
returns	C3	7	20
volatility spillovers	C3	7	19

Source: Own research

The semantic configuration of Cluster 3 (C3) indicates a body of literature that prioritizes empirical investment performance over the macro-institutional frameworks of green finance. The dominance of the term "renewable energy" endows this cluster with a pronounced sectoral and asset-centric focus. Concurrently, variables such as "oil prices," "risk," "returns," and "volatility spillovers" suggest that these assets are scrutinized through the lens of market efficiency and their sensitivity to external shocks. Furthermore, the integration of "climate finance" reflects a specialized academic discourse regarding the extent to which climate-aligned funding maintains a rigorous financial foundation and how it correlates with quantifiable energy and investment results.
Disciplinary validation corroborates this analytical orientation. As detailed in Table 8, the primary Web of Science (WoS) Categories associated with C3 are Economics (8 articles), Business, Finance (7), and Environmental Sciences (3). Similarly, the leading Research Areas include Business & Economics (14), Environmental Sciences & Ecology (3), and Science & Technology: Other Topics (2). This distribution confirms a cluster fundamentally rooted in economic and financial assessment, while retaining an essential link to energy transition and sustainability objectives. Unlike Cluster 1, C3 is characterized by an applied and performance-driven approach. Moreover, in contrast to Cluster 2, it shifts the focus from broad systemic transmission toward the specific interplay between renewable energy assets, risk exposure, and return dynamics.

Table 8. The top 3 categories from WoS Categories and Research Areas specific to the articles in Cluster 3

Cluster 3			
WoS Categories		Research Areas	
Category	Article number	Category	Article number
Economics	8	Business & Economics	14
Business, Finance	7	Environmental Sciences & Ecology	3
Environmental Sciences	3	Science & Technology - Other Topics	2

Source: Own research

Care and Weber (2023) offer a critical perspective by arguing that research in climate finance has frequently lacked the financial depth one might anticipate. This observation aligns with the primary function of Cluster 3 (C3) as a specialized analytical space where general climate-finance discourse is translated into rigorous financial and investment-oriented inquiries. Empirical support for this thematic focus is provided by Ftiti et al. (2025), who demonstrate that oil-price dynamics significantly influence transitions in renewable energy capacity through specific climate mitigation finance channels, thereby establishing an explicit nexus between energy prices, sustainable power, and financing. Additionally, Wang (2024) explores how exposure to carbon risk impacts the vulnerability of investment funds, further solidifying the cluster's commitment to risk-based financial analysis.

Together, these scholarly contributions confirm that C3 serves as the applied investment-performance segment of the field, where climate finance is systematically evaluated through the metrics of risk, return, and renewable-energy dynamics. In the context of the broader study, Cluster 3 addresses RQ1 by highlighting a distinct, albeit compact, research stream focused on the financial behavior of assets associated with the energy transition. It also informs RQ3, as the persistence of this cluster indicates a burgeoning interest in the asset-pricing and portfolio management implications of climate-oriented economic shifts.

Table 9 provides a comprehensive summary of the primary support papers for each cluster, detailing the specific studies that validate the thematic boundaries and disciplinary foundations of the identified research domains.

Table 9: Key support papers by cluster and their thematic relevance

Cluster	Autor support paper	Main relevance
C1	Luo et al. (2022)	maps sustainable finance and green transition hotspots
C1	Tiwari et al. (2024)	links green finance, innovation, and energy transition
C1	Dunbar & Treku (2025)	shows role of transition investment flows in green bond issuance
C2	Wu et al. (2024)	spillovers between green finance and traditional energy markets
C2	Wu & Qin (2024)	asymmetric volatility spillovers across green finance markets
C2	Bouri et al. (2022)	climate policy uncertainty and green/brown stock pricing
C3	Care & Weber (2023)	critiques and maps climate finance literature
C3	Ftiti et al. (2025)	oil prices, climate finance, and energy transition drivers
C3	Wang (2024)	carbon risk exposure and fund vulnerability

Source: Own research

Table 9 provides a structured synthesis of the foundational literature that substantiates the three thematic clusters identified in the bibliometric review. For Cluster 1, the table highlights the contributions of Luo et al. (2022), Tiwari et al. (2024), and Dunbar & Treku (2025), which collectively establish the macro-level linkages between green finance, energy innovation, and sustainable development commitments. Cluster 2 is validated by the research of Wu et al. (2024), Wu & Qin (2024), and Bouri et al. (2022), focusing on the intricate market mechanics of volatility spillovers, asset connectedness, and the pricing of climate policy uncertainty. Finally, Cluster 3 is anchored by Care & Weber (2023), Ftiti et al. (2025), and Wang (2024), whose work reinforces a more applied, performance-oriented domain centered on the risk-return dynamics of renewable energy assets and fund vulnerability to carbon risk. By aligning these specific academic works with the identified clusters, the table serves to confirm the thematic coherence and disciplinary integrity of the research landscape.

3.4. Bridges and TIE relations

The bridge analysis introduces a more nuanced layer of interpretation to the established cluster structure. Out of the 154 documents analyzed, 34 were categorized as "TIE," signifying that a considerable portion of the literature exists within intermediate conceptual spaces rather than being confined to a single thematic domain. This finding is particularly noteworthy as it demonstrates that the research field advances not only through increasing specialization but also through the strategic recombination of concepts across different themes.

The bridge analysis provides an additional dimension of interpretation for the existing cluster structure. Within the total corpus of 154 documents, 34 were identified as TIE, signifying that a meaningful portion of the literature resides in intermediate spaces rather than strictly within a single thematic category. This finding suggests that the domain is advancing not only via specialization but through the intellectual recombination of diverse themes.

As illustrated in Figure 2, the most prominent bridge relationship is found between C2 and C3 with 12 documents, followed by C1–C3 with 10 documents, C1–C2 with 8 documents, and a nexus of 4 documents that synthesize all three clusters simultaneously. Such a configuration demonstrates that the most vigorous research interfaces are situated at the intersection of market-risk analysis and renewable energy/climate finance, alongside the convergence of transition-focused green finance and investment performance studies. Ultimately, the field's most dynamic "border zones" transcend the simple connection between macro-level sustainability discourse and financial markets, actively integrating asset-specific risk-return analytics with broader energy transition narratives. Consequently, the TIE segment functions as a highly revealing analytical space rather than mere statistical noise.

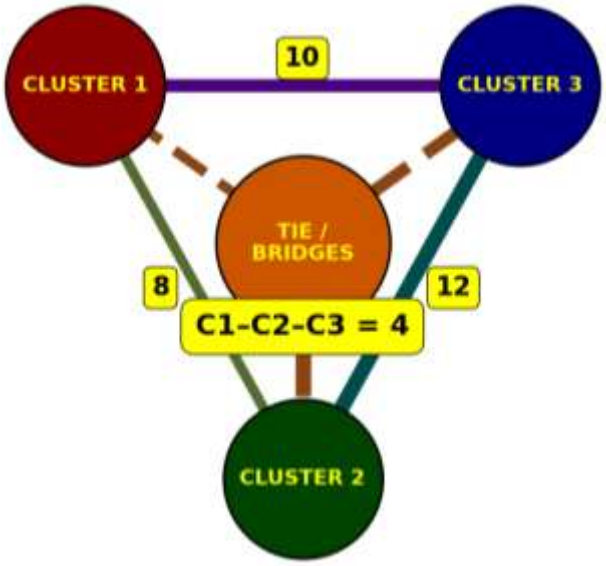

Figure 2. Visualization of Cross-Cluster Bridge Relations
Source: Own research

Thematic results from the TIE analysis offer a direct resolution to Research Question 2 by identifying recurring intellectual convergences at several critical junctures. These intersections specifically synthesize green finance with market uncertainty, renewable energy with return dynamics, and transition-based narratives with financial revaluation. Exemplifying this interdisciplinary bridge are studies such as Bouri et al. (2022), which investigates the impact of climate policy uncertainty on the valuation of green and brown energy equities, and Campiglio et al. (2025), which explores the correlation between central bank climate communications, financial market behavior, and the returns of green firms. Consequently, far from constituting statistical noise, the TIE segment represents a primary analytical dimension that encapsulates the most revealing thematic integrations currently shaping the research landscape.

4. Discussion

The results of this bibliometric inquiry demonstrate that the contemporary literature encompassing green investments, the energy transition, and financial markets is structured around an increasingly coherent, yet fundamentally tension-filled, intellectual architecture. In response to RQ1, the research domain is characterized by a dominant transition-oriented green finance core, which is complemented by a distinct segment focused on financial market risk and a more specialized cluster examining the performance dynamics of climate finance and renewable energy. This tripartite configuration indicates a paradigmatic shift in scholarly focus; the literature has progressed beyond the preliminary stage of justifying the relevance of green finance and is now deeply engaged in analyzing the specific mechanisms through which financial systems interface with market dynamics, regulatory signals, and investment performance outcomes.

A primary insight derived from this analysis is the foundational role of the relationship between green finance and the broader energy transition. The quantitative and conceptual dominance of Cluster 1 highlights a prevailing scholarly perspective that views finance not merely as a peripheral support system, but as a critical mechanism through which low-carbon transformations are institutionalized, scaled, and governed. This interpretation is supported by a growing body of work demonstrating that green financial development, the issuance of green bonds, and transition-aligned investment flows are intrinsically linked to the expansion of renewable energy capacity, the promotion of innovation, and the fulfillment of climate-related policy objectives (Tiwari et al., 2024; Dunbar & Treku, 2025; Ziolo et al., 2025). Furthermore, the evidence suggests this relationship is not strictly instrumental; finance actively recalibrates the

strategic and institutional architecture required to translate environmental mandates into economically actionable frameworks.

A secondary analytical insight emphasizes the transformative and active role of capital markets within the transition process. The literature increasingly rejects the view of markets as passive conduits for the transmission of decarbonization policies. Rather, the evidence from Cluster 2 and the associated bridge (TIE) analysis indicates that financial markets actively internalize climate-related signals, redistribute volatility across sectors, and facilitate the reconfiguration of asset relationships under conditions of pervasive uncertainty. High-frequency keywords such as green bonds, carbon pricing, and systemic connectedness are no longer treated as peripheral subjects; instead, they constitute the central analytical infrastructure of the field. Consequently, the energy transition is increasingly interpreted through the lens of financial-market processes as much as through industrial or policy-driven paradigms. Research in this area underscores that green assets and energy-related securities are integrated into dynamic systems of shock transmission, where valuation patterns are acutely sensitive to policy ambiguity, macroeconomic crises, and disturbances in commodity markets (Bouri et al., 2022; Wu et al., 2024; Wu & Qin, 2024; Sohag et al., 2023).

Finally, addressing RQ2, the study highlights the analytical significance of the "bridge zone" between thematic clusters. The results from the TIE analysis demonstrate that the most substantial thematic intersections within the literature are central to the field's evolution rather than marginal. The most robust intellectual interfaces are found at the nexus of market-risk analysis and renewable-energy or climate-finance performance, as well as the junction between broad transition-oriented finance and investment-outcome debates. This pattern suggests that the current body of literature resists rigid thematic compartmentalization. Studies situated at these interfaces address the most critical policy questions, such as how central bank climate communications modulate equity returns, how policy uncertainty influences the relative pricing of green and brown energy stocks, or how fluctuations in oil prices shape renewable energy adoption through climate-finance channels (Bouri et al., 2022; Campiglio et al., 2025; Ftiti et al., 2025). Ultimately, these integrated findings reveal several foundational tensions that continue to structure and define the research field.

4.1. Return versus sustainability

One of the most salient paradigmatic tensions identified within the contemporary scholarly landscape concerns the intricate and often conflicting relationship between orthodox financial performance metrics and normative sustainability objectives. While green assets are fundamentally conceptualized as critical strategic mechanisms for facilitating systemic decarbonization and enhancing climate resilience, they are concurrently subjected to rigorous evaluation through traditional investment benchmarks, such as risk-adjusted returns, asset pricing models, and idiosyncratic market sensitivity.

Within this context, Cluster 3 (C3) emerges as a pivotal analytical domain, as it effectively captures a specialized body of literature wherein broader climate-finance and renewable-energy discourses are operationalized into tangible inquiries regarding return dynamics, portfolio vulnerability, and exposure to exogenous volatility shocks. This thematic orientation is substantiated by the critical perspectives of Care and Weber (2023), who argue that climate research must maintain a more rigorous financial foundation, and Wang (2024), who investigates how carbon risk exposure directly influences fund vulnerability, thereby reinforcing the cluster's emphasis on applied, risk-based investment analysis. Consequently, the overarching implication is that green investment research is increasingly dictated by a sophisticated dual logic: it must demonstrably validate its environmental efficacy and ecological relevance while simultaneously maintaining empirical intelligibility and legitimacy for global investors through standardized financial metrics.

4.2. Transition risk versus investment opportunity

A second tension lies between the perception of the energy transition as a source of opportunity and its treatment as a source of risk. Cluster 1 emphasizes opportunity: green finance supports innovation, low-carbon development, and strategic transformation. Cluster 2 emphasizes risk: volatility spillovers, uncertainty, carbon pricing, and market revaluation. The field therefore oscillates between two interpretive frames. In one frame, transition creates new investment opportunities and expands sustainable capital markets. In the other, it generates new forms of uncertainty, contagion, and repricing. The coexistence of these frames is not contradictory; rather, it reflects the reality that transition processes produce both asset-creation and asset-reassessment dynamics.

The emphasis on opportunity within Cluster 1 is increasingly linked to the role of technological facilitators in driving the "twin transition" of greening and digitalization. In this context, Enache et al., (2025) argue that the integration of Internet of Things (IoT) technologies is vital for organizations aiming to align their operational strategies with sustainability goals. By providing a research instrument to assess IoT maturity, their work highlights how digitalization serves as a practical manifestation of the "innovation" and "strategic transformation" identified in the bibliometric network. This suggests that the "opportunity" side of the transition is increasingly defined by a firm's ability to leverage smart technologies to meet environmental targets.

Furthermore, the transition from viewing decarbonization as a systemic risk to a strategic opportunity often depends on the level of data-driven transparency within an organization. Enache et al. (2025) suggest that assessing the integration level of IoT technologies allows firms to better navigate the green and digital transition, potentially reducing the uncertainty associated with market revaluations. This implies that the "asset-creation" logic of the transition is bolstered by digital tools that provide the empirical basis for sustainable performance, effectively bridging the gap between volatile market signals and long-term innovation.

4.3. Policy support versus market logic

A third tension concerns the balance between policy coordination and market autonomy. The literature strongly suggests that policy credibility, climate commitments, carbon pricing, and central-bank communication matter for green financial outcomes (Bouri et al., 2022; Campiglio et al., 2025). Yet the market clusters also show that financial systems respond according to their own logics of pricing, uncertainty, and interdependence. This means that public support alone is insufficient unless it is accompanied by stable signaling environments and institutions capable of reducing ambiguity. Conversely, market-based development of green finance can remain shallow or volatile if policy frameworks are fragmented or weakly credible. The field therefore points toward a co-dependence between transition governance and market functioning.

Within this framework of co-dependence, the emergence of decentralized technologies offers a potential pathway to bridge the transparency gap between policy intentions and market execution (Arghira et al., 2022). As Tiganoaia & Alexandru (2023) demonstrate, blockchain-based decentralized platforms can significantly enhance transparency and efficiency in the mobilization of capital for sustainable development goals. By utilizing smart contracts and decentralized protocols, such systems provide a technical solution to the issues of ambiguity and lack of trust often associated with traditional centralized funding methods. This suggests that the "stable signaling environments" required for effective green finance may increasingly rely on technological transparency to verify the impact of transition-related investments.

Furthermore, the integration of such decentralized applications suggests that aligning "market logic" with sustainability objectives requires more than just policy mandates; it requires infrastructure capable of ensuring that funds reach their intended beneficiaries. Tiganoaia and Alexandru (2023) highlight how blockchain architecture allows for the secure and transparent

tracking of contributions, particularly for social and educational causes within the context of sustainable development. In this sense, decentralized crowdfunding serves as a mechanism for reducing the informational asymmetry that often hampers market-based green finance, ultimately strengthening the link between institutional governance and efficient capital allocation.

4.4. Institutional investors versus retail-oriented market behavior

Furthermore, the effectiveness of the strategic role played by institutional investors in the energy transition is increasingly dependent on the internal organizational capacity of firms to translate capital into measurable performance. While long-term portfolio orientation relies on financial screening, the underlying drivers of corporate success are shifting toward technological and human-centric pillars. As Barbu et al., (2025) demonstrate, the integration of workplace technology and the prioritization of employee satisfaction are essential intermediate objectives for achieving the high-level performance that strategic investors seek.

This perspective adds a critical dimension to the debate between strategic allocation and reactive market behavior. A truly strategic investor must look beyond short-term sentiment and evaluate how companies adapt to digital pillars and employee needs to ensure resilience in dynamic market contexts. Therefore, the "strategic" nature of institutional capital may be best defined by its ability to identify firms that successfully leverage technology to enhance operational excellence and professional development, thereby securing sustainable long-term returns.

4.5. Implications for the European Union and emerging markets

The discussion also has a clear regional relevance. For the European Union, the results are important because they highlight the need to align green-finance expansion with energy-transition strategy, capital-market depth, and credible regulatory communication. In the European context, where sustainable finance frameworks are especially visible, the challenge is not only to expand green financial instruments but also to stabilize the informational and policy environment in which they operate. For emerging markets, the findings point to a somewhat different issue: how to scale green investment and renewable-energy finance despite higher exposure to market volatility, policy inconsistency, and capital-market fragility. The literature suggests that the success of green finance in these contexts depends on both institutional credibility and the ability to manage risk transmission from energy and commodity markets.

4.6. Future research agenda

In response to RQ3, this bibliometric review delineates several strategic pathways for future scholarly inquiry. Primarily, there is an imperative need to enhance the empirical "financial quality" of climate finance research. As argued by Care and Weber (2023), the existing literature has frequently lacked a sufficiently rigorous financial foundation, establishing this as a critical agenda for the discipline. Consequently, future investigations should strive to synthesize climate-finance discourse more explicitly with established frameworks of asset pricing, portfolio risk management, and capital-market development.

Furthermore, the results of the bridge analysis indicate significant potential for exploring cross-cluster interfaces. Future research should specifically target the intersections between green finance and policy uncertainty, as well as the mechanisms governing volatility transmission within renewable-energy assets. There is also a compelling need to investigate how climate-related communications influence market revaluation and to further examine the relationship between carbon-risk exposure and the vulnerability of investment funds.

Simultaneously, there is substantial scope for expanded comparative analysis across diverse geographical regions, particularly by contrasting mature green-finance ecosystems with those in more volatile or institutionally constrained markets. Such cross-regional evaluations would clarify whether the observed cluster configuration is a global constant or a reflection of a literature

currently skewed toward specific regulatory and market environments. Additionally, future scholarship must address investor heterogeneity with greater precision, accounting for the distinct behavioral and strategic profiles of institutional investors, various fund types, and broader market participants. While the current literature acknowledges these differences, they have yet to be mapped in a systematic or comprehensive manner.

Finally, the field would derive significant benefit from a more cohesive integration of transition-governance research and capital-market microstructure. Although the present review demonstrates that these dimensions are becoming increasingly intertwined, they are still predominantly analyzed through parallel rather than unified analytical frameworks

5. Conclusions

This investigation provided a systematic bibliometric synthesis of contemporary literature at the intersection of green investments, the energy transition, and financial markets, analyzing a corpus of 154 documents indexed in the Web of Science Core Collection from 2021 to 2025. By employing VOSviewer-based co-occurrence mapping, thesaurus normalization, and cluster validation via Web of Science (WoS) Categories and Research Areas, alongside a specialized TIE/bridges analysis, the study delineated a coherent three-cluster architecture. The resulting scholarly landscape is fundamentally organized around three core domains: green finance and sustainability-oriented transitions; financial-market risk and transmission mechanisms; and the nexus of climate finance, renewable energy, and return dynamics.

The primary theoretical contribution of this research lies in its clarification of both the internal thematic structure of the field and its critical bridge zones. The review demonstrates that recent scholarship has progressed beyond fragmented discussions of renewable energy or green finance in isolation to increasingly examine the complex interfaces among financial markets, policy uncertainty, transition risk, and investment performance. This integration is most pronounced within the TIE segment, where multi-cluster studies illuminate the strongest areas of thematic convergence, thereby offering a descriptive map and an interpretive framework for understanding the evolving economic and financial dimensions of the energy transition.

The findings yield significant practical implications for diverse stakeholders. For the research community, the results suggest that future inquiries should explicitly prioritize cross-cluster relations, the financialization of climate finance, investor heterogeneity, and regional market dynamics. For policymakers, the analysis indicates that the effectiveness of green-finance strategies is contingent not only on the availability of financial instruments but also on maintaining policy credibility, establishing stable market signals, and implementing institutional mechanisms to mitigate transition-related uncertainty. Furthermore, for investors and market participants, the results underscore that green assets are inextricably embedded in broader systems defined by market volatility, carbon exposure, commodity-price fluctuations, and institutional communication.

Consistent with the inherent constraints of bibliometric research, this study is delimited by its reliance on a single database, a specific conceptual query, and a defined temporal window. Additionally, the interpretive structure is influenced by methodological parameters such as keyword normalization, occurrence thresholds, and cluster assignment rules. Despite these limitations, the review offers a robust and current synthesis of a rapidly accelerating research domain. Future scholarly efforts can expand upon this foundation by broadening database coverage, evaluating alternative search strategies, and deepening the investigation of bridge themes and regional configurations. Ultimately, this study concludes that as the literature on green investments and the energy transition becomes more expansive and interconnected, the necessity for integrated economic analysis continues to intensify

6.References

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