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Review

The Nexus Between Green Bonds, Green Credits, and the Energy Transition Toward Renewable Energy Sources: State of the Art

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Abstract

The transformation of the energy market toward renewable finance is achieved primarily through green innovations, which require sources of funding. The aim of this article is to show the state of research on green credit and green bonds in the context of their role in financing the green transition of the energy market. The article uses a critical literature review supported by VoSviewer software and quantitative analysis. While most literature reviews cover green finance or sustainable finance in the energy transition process (macro level), our attempt refers to the level of financial instruments (micro level); we demonstrate the significant role of green credit and green bonds in financing energy transition and the high degree of differentiation in the functionality of both instruments. Specifically, green bonds strongly accelerate green innovation in the energy sector and stimulate energy transition through green credits. Articles from the second typological group identified in the study clearly emphasize this relationship. The remaining key findings highlight the dominant share of developed countries as a base for research and analysis, as well as large enterprises, which were the primary focus of the study.

Keywords: sustainability; energy market; financial market; green financial instruments

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1. Introduction

Energy transition has become a fact; most countries have adopted public programs and policies in this area. Still, the question of the role of financing in this process of change toward renewable energy sources has remained unresolved [1]. The impact of ESG (environmental, social, governance) risk on society and the economy makes it necessary to take adaptive actions to mitigate the outcomes it entails. This is particularly true for the risk of climate change and the transformation of the energy sector [2]. It is known that this sector is responsible for greenhouse gas emissions, which drive climate risk [3]. Energy market transformation is a complex issue. Research in this area is usually interdisciplinary and uses many research methods. Published papers on financing energy transition typically focus on a global perspective, i.e., the role of renewable/green/sustainable finance in funding-related projects. This approach, though, fails to emphasize or analyze the role of individual financial instruments, rather generalizing the importance of green or sustainable finance [4–6]. In a different research approach, risk and financial instruments that support the transformation are examined along with the relationship between financial development and energy market transition [7,8]. However, publications that focus on the analysis and state of research on the most popular financial instruments supporting green transition in the context of energy market changes, green credit and green bonds [9], other than the general perspective of green finance, are few. The research on green credit in the context of energy transition mainly covers the impact on energy efficiency, green credit policy in China, the relationship with R&D, and the impact on investments in renewable energy [10,11]. In turn, articles on green bonds in the energy market context discuss the advantages and disadvantages of green bonds, financing the low-carbon transition, and the impact on energy transition of enterprises [9,12].

This article sets out to fill this gap by analyzing the state of publications in this area. This is important since green credit and green bond instruments are used to fund green innovations, without which the transition toward renewable energy sources would be a futile endeavor. The aim of this article is to show the state of research on green credit and green bonds in the context of their role in financing green transition of the energy market.

In particular, the article answers the following research questions:

1. What research problems dominate in the analyses?
2. Where are the research works published?
3. What regions are the leaders in research?
4. What enterprises are studied?

The paper is organized as follows: Section 1 gives an introduction. Section 2 presents a literature review. Section 3 explains the research method and methodological framework. Section 4 presents the results of the research. Section 5 provides a discussion. Section 6 outlines the conclusions.

2. Literature Review

Energy transition, understood as the process of moving from the use of fossil fuels to renewable energy sources (RES), is one of the key tools for achieving the Sustainable Development Goals [13,14], in particular SDG 7 (clean and affordable energy) [15–18] and SDG 13 (climate action) [19–21], and both of these goals in parallel.

Increasing the share of renewable energy sources (RES) in the energy mix is the foundation of low-emission energy development and is crucial for cutting carbon dioxide emissions [22]. However, it should be emphasized, as Tian et al. [23] rightly note, that the issue of energy transition should not be limited solely to reducing greenhouse gas emissions—the so-called “carbon tunneling”—without taking into account the full social and environmental aspects, e.g., health issues [24] or quality of life [25]. Additionally, energy transition contributes to improving energy security [26–28] and has a positive impact on the economy by supporting innovation, technological development [29,30], productivity growth, and reducing energy production costs [31,32].

The energy transition process is complex, multidimensional, and iterative. Markard and Rosenbloom [33] distinguished four phases of the net-zero energy transition. These stages should be viewed as mutually reinforcing and partially overlapping because, along the path to subsequent phases, new processes emerge that coexist and interact with existing ones (Figure 1).

The energy transition process relies on the cooperation of multiple actors, interconnections between systems, and comprehensive policy support [34]. The importance of regulatory frameworks in this process was highlighted in independent studies by Alka et al. [35] and Apata [36]. They demonstrated that the integration of modern technological and organizational solutions with the regulatory framework is an indispensable condition for a lasting change in the energy market structure. Alamooti and Alamooti [37] demonstrated that countries with strong and coherent policy frameworks outperformed others by approximately 7.5% in adopting renewables and by 6.2% in improving energy efficiency, compared with nations having underdeveloped regulations.

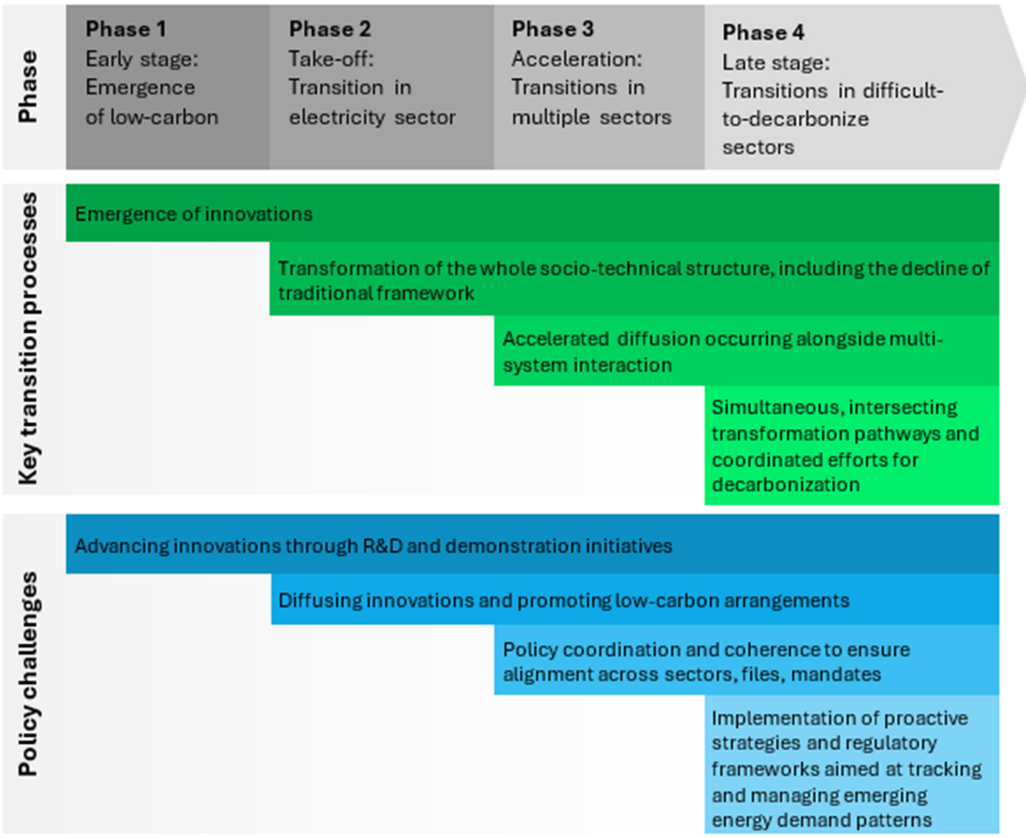

Figure 1. Phases of the net-zero energy transition.

Energy transition is a long-term and highly capital-intensive process, one that requires extensive infrastructure and technology investments [38]. According to BloombergNEF [39], global investment in clean energy reached USD 2.1 trillion in 2024, yet aligning with net-zero targets may require annual funding at as much as USD 5 trillion. Numerous studies indicate that finance is a key factor in the effectiveness of energy transition. The ability to mobilize capital at an appropriate scale and structure, and at an acceptable cost [40–43], determines the pace of deployment of low-emission technologies and the development of infrastructure supporting the decarbonization process [44].

The specific nature of transition-related projects necessitates securing external financing for their delivery. The choice of financing sources depends closely on the structure of a country's financial system. In countries based on the German–Japanese system, commercial banks remain the main capital provider [45,46], while in countries with a continental model, capital markets are playing a growing role in funding transition projects [47,48].

In this context, it is particularly important to identify and analyze the mechanisms for financing energy transition—both in terms of the nature of the instruments used (from traditional ones, such as grants, subsidies or taxes, to modern market solutions, e.g., mechanisms for setting emissions prices, renewable energy certificates, feed-in tariffs), and the degree of involvement of the public and private sectors in financing this process (Figure 2).

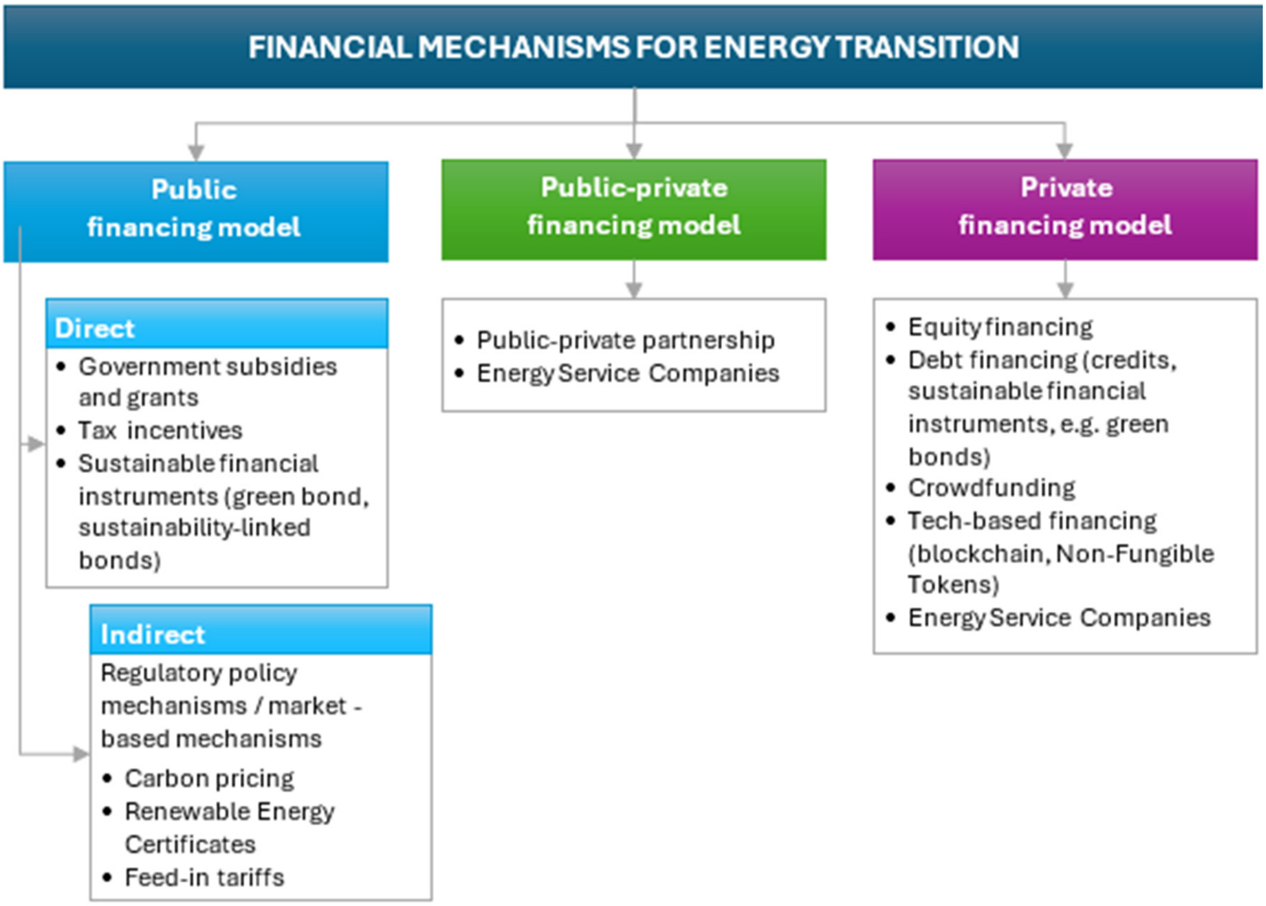

Figure 2. Financial mechanisms for energy transition.

The high capital demand, complexity, and long-term nature of transition-related projects have led to growing interest among researchers and policymakers in the concept of green finance. This term refers to the redirection of capital flows toward projects that deliver environmental and social benefits [49]. As defined by the OECD [50], green finance encompasses activities that "increase financing and investment in technologies, infrastructure, and businesses that will be crucial in the transition to a low-carbon, climate-resilient, and resource-efficient economy."

The importance of green finance is strongly supported by both theoretical literature and empirical research. For example, Sun et al. [51], demonstrated that, based on data spanning from 2010 to 2021, green finance plays a significant role in reducing environmental pollution at the national scale. Similarly, Zhang et al. [52], using data from G20 countries (2008–2018), confirmed the positive impact of green financial instruments on reducing CO_2 emissions. Wang et al. [53], based on a panel data analysis from 100 developed and developing countries, showed that green real estate financing significantly reduces CO_2 emissions, especially in emerging economies.

Green finance can be implemented through various financial instruments, depending on the investment rationale, type of beneficiaries, time horizon, and the nature of environmental risk. An overview of the available instruments and the main research directions in this area is presented in Table 1.

Table 1. Types of green financial instruments and main research areas.

Type of Green Financial Instrument	Main Research Areas
Green Bonds	Part of green finance [54–57]; sustainable development [58,59]; energy transition [60–63]; innovation [64–66]; disclosure [67,68]; financial performance [69,70].
Green Loans (Green credit)	Part of green finance [54,71,72]; sustainable development [73,74]; energy transition [75–78]; innovation [79,80]; financial performance [81–84].
Sustainability-Linked Bonds (SLBs)	Market development and pricing [85–87]; transparency, credibility, and greenwashing [88,89]; ESG outcomes and economic efficiency [87,90,91].
Sustainability-Linked Loans (SLLs)	Market development and pricing [92]; economic efficiency [93–96].
Green Certificates/Guarantees of Origin)	Effectiveness of energy policy tools and regulatory impact [97–99]; market dynamics and pricing [100,101].

Based on the summary provided in Table 1, the most frequently studied green finance instruments in the context of energy transition are green bonds and green loans/credits. Their popularity stems from their key role in financing projects related to renewable energy sources, improving energy efficiency, and developing low-emission infrastructure [61,63]. Despite the growing number of publications on these instruments, the research remains fragmented, often focusing solely on one form of financing, without an attempt to compare different instruments. Therefore, comprehensive approaches which would systematically and coherently summarize the current state of knowledge in this area are missing.

A comparative perspective on green bonds and green loans takes on particular significance in the context of institutional conditions, especially the diversity of financial systems. Green loans are more common in systems where commercial and public banks play a strong role, whereas green bonds tend to develop more dynamically in environments with widespread and well-regulated access to debt capital markets. Furthermore, the nature of these instruments translates into differences in investment risk, payback period, accessibility for beneficiaries, and compliance with national climate policies.

The uniqueness of this study is found not only in a synthetic summary and comparison of the most frequently used green finance instruments, but above all in the consideration of the institutional and systemic conditions that determine their use and effectiveness in financing energy transition.

3. Material and Method

This study employed a literature review methodology consistent with the approach proposed by Snyder [102], encompassing four main stages: review design, conduct, data abstraction and analysis, and structuring and writing the review. The research process was initiated by defining the main objective of the study and formulating specific research questions.

The aim of this analysis is to present the current state of knowledge on green loans and green bonds in the context of their role in financing energy transition. Specifically, the following research questions were asked:

- What research issues dominate the analyzed literature?
- Which journals most frequently publish papers on the discussed topics?
- Which geographic regions are leading the way in green finance research?
- What types of enterprises are most frequently analyzed in publications?

Publications were searched using the Web of Science database. The search process was based on carefully selected keywords, using Boolean operators (e.g., AND) and quotation marks to enable a precise search of complex expressions:

(1) ("green bond*" OR "green credit*") AND "energy transition",
(2) ("green bond*" OR "green credit*") AND "energy transformation",
(3) ("green bond*" OR "green credit*") AND "renewable energy sources".

To enhance the consistency of the results, the search was limited to publications in English, with no time restrictions applied. A two-stage process of article qualification for further analysis was implemented (screening and eligibility in Figure 3). In the first stage, three researchers independently screened the titles and abstracts of all publications retrieved from the Web of Science database, using predefined inclusion criteria developed specifically for this study. Data extraction was performed using a pre-developed research form, enabling a systematic collection of key information from individual publications. The collected data included the following, among others: year of publication, methodology used, data sources, regions covered by the analysis, level of development of the countries studied, size of the analyzed enterprises, research directions, and the main findings and relationships presented in the studies. In cases of disagreement, the researchers discussed their assessments until the consensus was reached. This was followed by a full-text review, using the same criteria, which ultimately determined the inclusion of articles for further analysis. No automation tools were used during the selection process—all decisions were made manually to ensure consistency and methodological rigor.

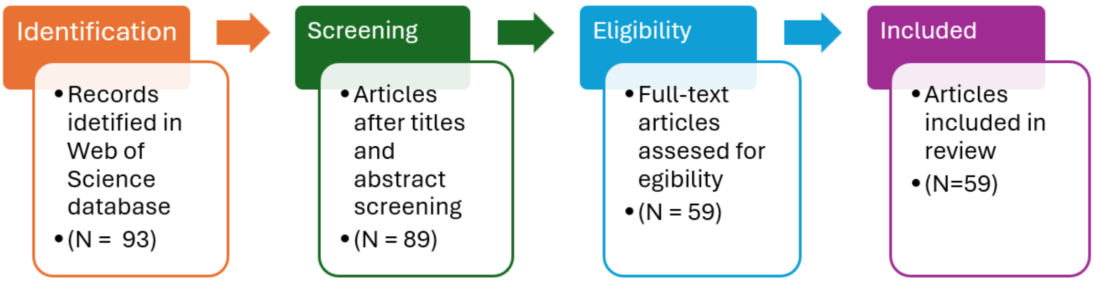

Figure 3. Diagram of the process of articles selection.

Based on this consolidated dataset, an in-depth literature analysis was conducted, the results of which are presented in the following sections of the article (Figure 3).

VOSviewer software (version 1.6.20) was employed to identify co-occurrence of keywords and terms recurring in the analyzed publications. At first, a map of the keywords was created with the minimum number of co-occurrences set to 4, which allowed for the identification of 29 keywords most frequently featuring in the analyzed publications (Figure 4). They were grouped by the software into five clusters, which are as follows:

- Cluster 1.1 (red color): energy efficiency, energy transition, finance, green credit, impact, optimization, renewable energy investment, supply chain, sustainability;
- Cluster 1.2 (green color): carbon neutrality, climate change, CO_2 emissions, economic growth, empirical evidence, green finance;
- Cluster 1.3 (lavender color): consumption, financial markets, innovation, policy, renewable energy;
- Cluster 1.4 (blue color): emissions, financial development, growth, OECD, renewable energy transition, sustainability;
- Cluster 1.5 (yellow color): green bonds, green credit policy, sustainable development.

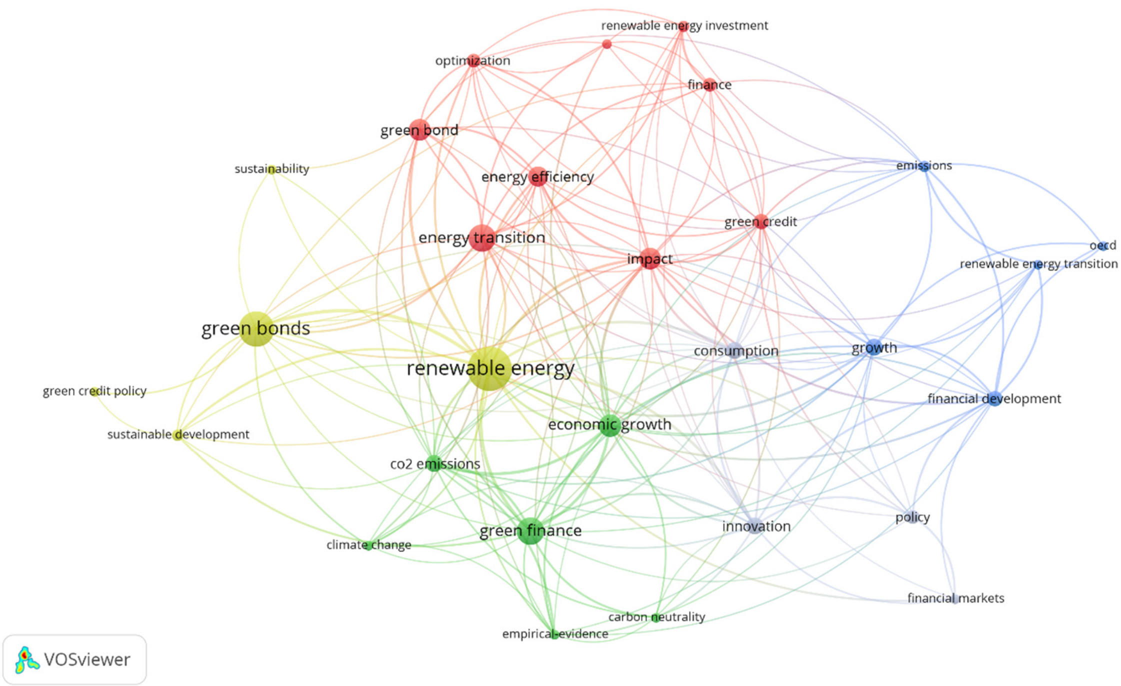

Figure 4. Visualization of co-occurrence of the keywords.

Cluster 1.1 focuses on technical aspects of energy use (efficiency, optimization) and financing energy transition (finance, green credit, renewable energy investment) in the context of sustainability. Cluster 1.2 mainly includes concepts related to climate and climate change (climate change, CO_2 emissions, carbon neutrality) and links them to economic growth and green finance. The third cluster (1.3) points to the link between financial markets and renewable energy policy, as well as consumption (likely energy consumption) and innovation. Cluster 1.4 focuses on financial development and economic growth in relation to the transition toward renewable energy and enhanced sustainability, particularly within the context of OECD countries. Finally, Cluster 1.5, the smallest of all, highlights the connection between sustainable finance (green bonds, green credit) and sustainable development.

Another map was created based on terms recurring in the titles and abstracts of the analyzed publications (Figure 5). A minimum occurrence threshold of 10 was applied, which allowed for the identification of the most frequently featuring terms, of which the most relevant 60% resulted in a total of 18 items. These items were grouped into three clusters:

- Cluster 2.1 (red color): economic growth, energy, environment, financing, green finance, sustainable development;
- Cluster 2.2 (green color): climate change, energy transition, innovation, investor, policymaker, relationship;
- Cluster 2.3 (blue color): carbon emission, China, energy efficiency, evidence, green financing.

Cluster 2.1 focuses on the relationship between economic growth, environment, and sustainable financing. The terms suggest a thematic emphasis on how green finance supports sustainable development and energy-related economic strategies. Cluster 2.2 centers around the link between climate change and the roles of innovation, investors, and policymakers in energy transition. Cluster 3.1 brings together concepts related to carbon emissions and energy efficiency, with a strong geographical focus on China, and also includes green financing.

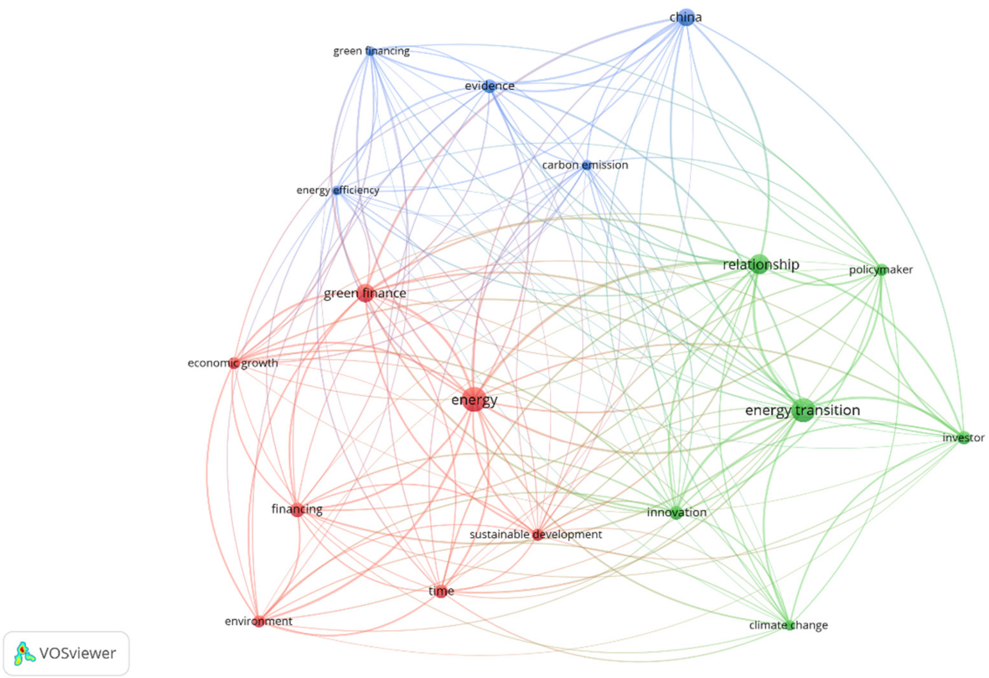

Figure 5. Visualization of co-occurrence of the recurring terms.

The study covers papers published between 2019 and 2025. Throughout this period, a clear upward trend in the number of publications can be observed, although the increase cannot be noted every year (Figure 6). The first decline occurred in 2020, when the number of publications dropped by half compared to 2019. In the following years, a gradual increase is noticeable, leading to a sharp rise in 2023, when the number of publications was more than four times higher than in 2022. However, in 2024, there was another decline, this time by approximately one-third. In 2025, there was another totable surge in the quantity of publications. Although the data only covers the first half of the year, the number of publications has already exceeded that of 2023.

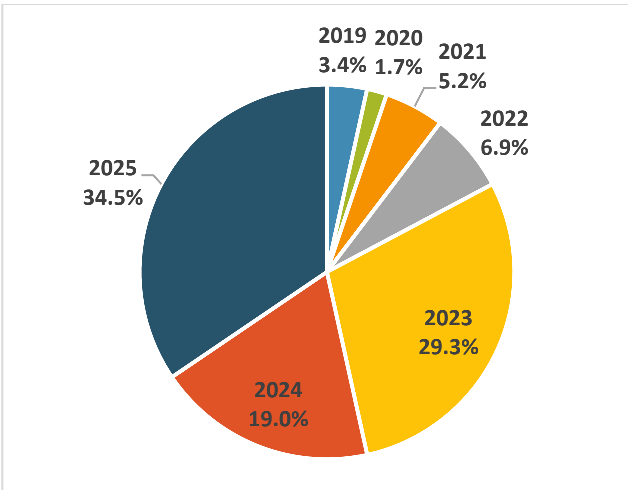

Figure 6. Publications by years.

Data-driven studies constitute a vast majority (83.6%) of the studies presented in the analyzed publications (Figure 7). A total of 8.2% of the studies used literature reviews as the basis, and 6.6% were case studies. Survey studies had the smallest share at 1.6%.

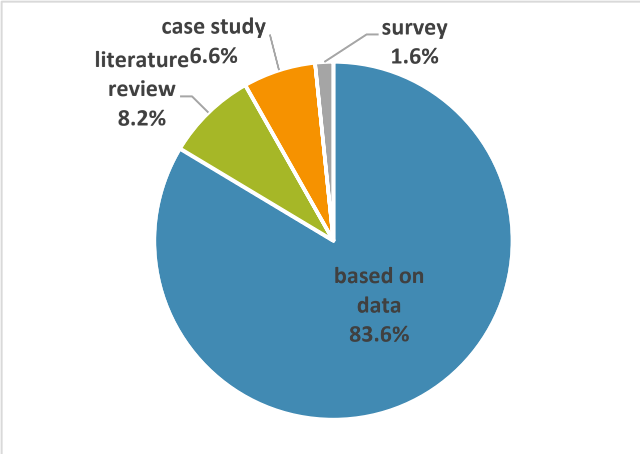

Figure 7. Types of studies.

The most frequently used data provider was S&P Global and its Green Bond Index data. It accounted for 20.5% of all data sources used in the research presented in analyzed publications (Figure 8). Bloomberg MSCI data, which also presents the Green Bond Index, took second place with about half the share of S&P Global (10.3%). China Stock Market and Accounting Research (CSMAR), CUFE-CNI High Grade Green Bond Index, LSEG (formerly Refinitiv) and World Bank each had a 5.1% share. The remaining sources had a small share individually, but were numerous, so in total they accounted for 48.8% of all data sources used.

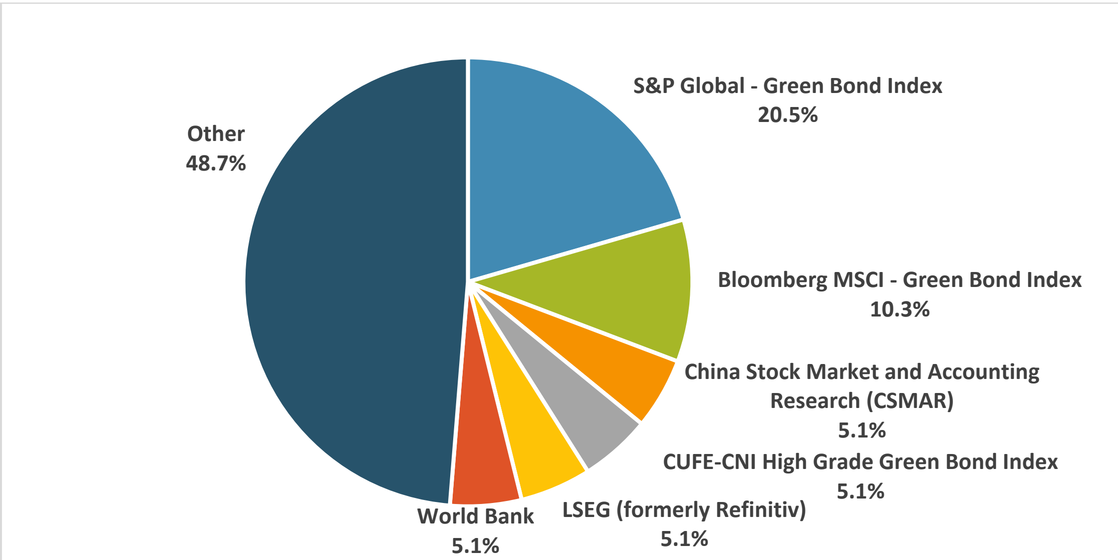

Figure 8. Data sources used for research in publications.

Among the regions covered by the research, Asia had the largest share, appearing in 91% of the publications (Figure 9). Studies on Europe came second at 45%, which is only half of the Asia share. Americas were found in 43% of the studies each. Next in line was Africa (36%), and the last was Australia (33%). Of note, many publications focused on studies concerning several regions; hence, the sum of the regional shares exceeds 100%.

In terms of the development status of the countries included in the research presented in the publications, the majority were developed countries (83%). Developing countries were the subject of 43% of the research, and here, as before, some of the research concerned both groups of countries.

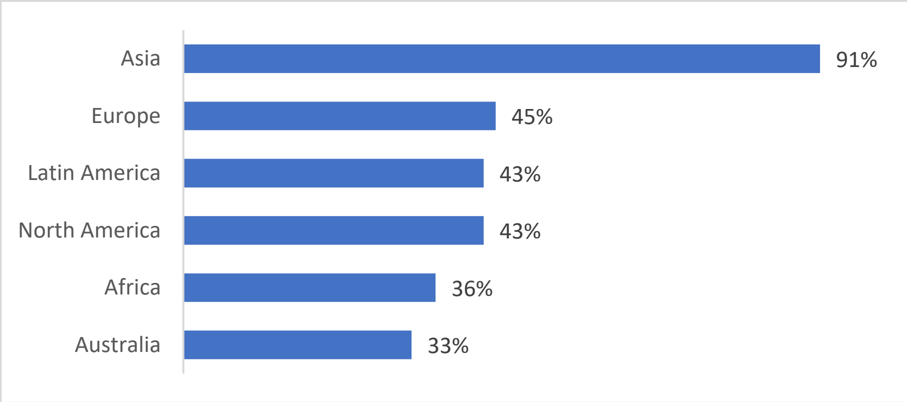

Figure 9. Regions under study.

Among the studies concerning enterprises, those focusing on large companies were the most common (71%), followed by medium-sized companies (67%), while studies on small businesses had the lowest share (60%). However, as shown, the differences in the number of studies by company size were not large.

The article uses multivariate correspondence analysis to identify relationships between selected keywords related to green bonds, green credit, and energy transition. For this purpose, thirty categorization variables relevant to the research area and issues discussed in scientific publications were created. These included the following: year of publication, size and type of enterprises, continent of origin of the authors, as well as the impact of green bonds and green credits on energy transition. All variables are binary, with "yes" indicating the occurrence of the phenomenon (coded as 1) and "no" indicating its absence (coded as 0).

The following variables and their categories were adopted for the study:

X_1—release year 2024 or later;
X_2—small enterprises;
X_3—medium enterprises;
X_4—large enterprise;
X_5—investment funds and insurance;
X_6—manufacturing/production;
X_7—service;
X_8—brown company (heavy polluting company);
X_9—municipal green bonds and government bonds;
X_{10}—city/cities;
X_{11}—bank;
X_{12}—authors' continent of origin: Europe;
X_{13}—authors' continent of origin: North America;
X_{14}—authors' continent of origin: Latin America;
X_{15}—authors' continent of origin: Asia;
X_{16}—authors' continent of origin: Australia;
X_{17}—authors' continent of origin: Africa;
X_{18}—developing countries;
X_{19}—developed countries;
X_{20}—GBCO (green bonds have a stronger impact on reducing CO_2);
X_{21}—GBIET (green credit intensification of the energy transition);
X_{22}—GBRC (green bonds reduce cost);
X_{23}—GBRES (green bonds support technological innovation in renewable energy);
X_{24}—GBRR (green bonds reduce risk);

X_{25}—GBS (stakeholder interest stimulates the growth of the green bond market);
X_{26}—GCCO (green credits have a stronger impact on reducing CO_2);
X_{27}—GCF (green bonds finance the energy transition);
X_{28}—GCIET (green bonds intensification of the energy transition.);
X_{29}—GCRES (green credit support technological innovation in renewable energy);
X_{30}—GCRR (green credit reduce risk).

The correspondence analysis module in the Statistica 13.3 package was used for calculations and visualization of results. Correspondence analysis is a method of multivariate statistical analysis. It allows for accurate identification of the co-occurrence of categories of variables (or objects) measured on a nominal scale [103–106]. The analysis begins with the construction of a detailed contingency table (cross tabulation) which consists of the specific categories of variables employed to define n objects. In practical applications, the Burt matrix is a commonly used format for recording such data. The first step involves generating a comprehensive indicator matrix denoted as Z, which consists of submatrices corresponding to individual variables: $Z = [Z_1, \ldots, Z_Q]$, where Q represents the number of characteristics. Each element in the indicator matrix takes on a binary value—0 or 1—indicating whether a given object possesses a particular category of a variable.

The Burt matrix is derived from the equation $B = Z^T Z$. Then, we obtain the symmetrical block matrix with diagonal matrices containing the number of categories of characteristics, and outside the diagonal matrix there are contingency tables for each pair of analyzed variables. The total number of each submatrix equals the number of analyzed n units, and the total number of Burt matrix amounts to $n \cdot Q^2$. Since the Burt matrix is symmetrical ($b_{ij} = b_{ji}$), the limit for the number of columns and rows is the same and may be determined by applying the following formula:

$$\sum_{j=1}^{J} b_{ij} = b_{i\bullet} = b_{\bullet j=Q} = Q \cdot b_{ii} \tag{1}$$

where

b_{ij}—components of the Burt matrix,

J—total number of categories of all characteristics.

The dimension (K) of the genuine co-occurrence space was calculated according to the formula below:

$$K = \sum_{q=1}^{Q} (J_q - 1). \tag{2}$$

Greenacre's criterion suggests that the optimal dimension for projecting variable categories is the one whose eigenvalues satisfy the following condition: $\lambda_{B,k} > \frac{1}{Q}$.

In addition to the standard criterion for identifying significant eigenvalues $\lambda_{B,k} > \frac{1}{Q}$, Greenacre introduces an approach aimed at enhancing the results of analyses based on Burt's matrix [105]:

$$\tilde{\lambda}_k = \left(\frac{Q}{q-1}\right)^2 \cdot \left(\sqrt{\lambda_{B,k}} - \frac{1}{Q}\right)^2 \tag{3}$$

where

Q—the number of variables,

$\lambda_{B,k}$—k-th eigenvalue.

4. Results

Based on thirty variables, each of which was categorized according to the characteristics of the research material, the Burt matrix was constructed. Based on Formula (2), the dimension of the actual co-occurrence space for responses to the analyzed questions was determined to be 30.

Next, we assessed the extent to which the eigenvalues in the reduced dimensional space explained the total inertia (λ = 1.000). To evaluate their significance to the study, we employed Greenacre's criterion, which deems principal inertias greater than $\frac{1}{Q} = \frac{1}{30} = 0.033$ to be significant. These significant inertias are coupled with K values up to 10 as shown in Table 2. To improve the quality of the mapping, we applied an eigenvalue adjustment in accordance with Greenacre's proposal (Formula (3)). Table 2 shows the eigenvalues λ_k (squares of the singular values γ_k), the principal inertia contribution to the total inertia (percentage inertia λ_k/λ), and the impact of eigenvalues from the K dimension on the overall inertia (cumulative percentage τ_k) prior to and after modification.

Table 2. Singular values and eigenvalues with the degree of explanation of total inertia in the original and modified versions.

K	Peculiar Values γ_k	Own Values λ_k	λ_k/λ	τ_k	$\tilde{\lambda}_k$	$\tilde{\lambda}_k/\tilde{\lambda}$	$\tilde{\tau}_k$
1	0.4522	0.2045	20.4485	20.4485	0.4371	17.7243	17.7243
2	0.3963	0.1571	15.7059	36.1544	0.3804	15.4232	33.1476
3	0.2719	0.0739	7.3923	43.5467	0.2550	10.3373	43.4849
4	0.2598	0.0675	6.7509	50.2976	0.2429	9.8477	53.3326
5	0.2352	0.0553	5.5338	55.8314	0.2183	8.8525	62.1851
6	0.2152	0.0463	4.6320	60.4634	0.1984	8.0449	70.2299
7	0.2130	0.0454	4.5374	65.0009	0.1962	7.9559	78.1859
8	0.2033	0.0413	4.1335	69.1344	0.1866	7.5657	85.7516
9	0.1937	0.0375	3.7503	72.8846	0.1770	7.1781	92.9297
10	0.1910	0.0365	3.6468	76.5314	0.1744	7.0703	100.0000
					$\tilde{\lambda}_k = 2.4663$		

To determine the best projection dimension, a graph of all non-zero eigenvalues was plotted (Figure 10). If the graph shows a decrease in value and then a flattening of the curve, then the proper projection space is the space indicated by the eigenvalue number just before the bend in the curve, the so-called "elbow". The tendency indicated by the curve linking eigenvalues implies that the space that represents the co-occurrence of variable categories should not exceed five dimensions. They constitute more than 62% of the inertia correlated with the analyzed data array.

The new coordinate values in the five-dimensional space for the variable categories were calculated using the following formula:

$$F^{\sim} = F\hat{}* \cdot \Gamma\hat{}(-1) \cdot \Lambda^{\sim} \quad (4)$$

where

$F^{\sim}$—matrix of new coordinate values for categories of variables (dimension 60 × 5),
F^*—matrix of original coordinate values for categories of variables (dimension 60 × 5),
$\Gamma\hat{}(-1)$—diagonal inverse matrix of singular values (dimension 5 × 5),
$\Lambda^{\sim}$—diagonal matrix of modified eigenvalues (dimension 5 × 5).

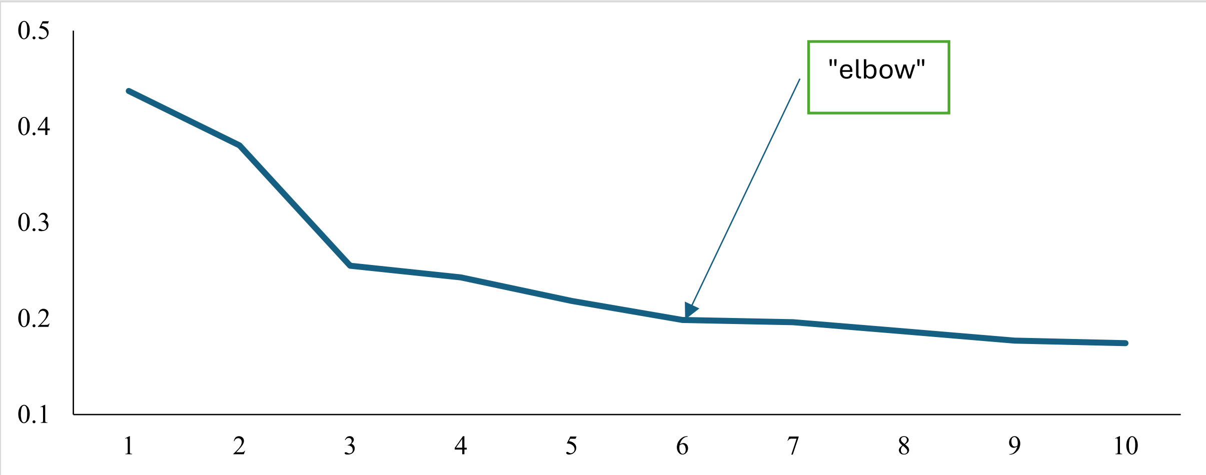

Figure 10. Graph of eigenvalues.

As it was impracticable to graphically present variables and their variants in a five-dimensional space, one of the agglomerative clustering methods was used—the Ward method [107,108]—which enabled the identification of relationships among different variable variants. The first clear increase in agglomeration distance between linkage stages served as the basis for selecting the optimal number of clusters. The critical distance value at which the merging of clusters ceased was determined using the metric proposed by Grabiński [109]:

$$q_i = \max_i \left\{ \frac{d_i}{d_{i-1}} \right\} \quad (5)$$

where

i = 2, 3, . . ., n − 1,

d_i—length of the i-th bond (i-th branch of the tree).

In Figure 11, presenting the linking of categories into classes, the stage at which the linking of classes was interrupted is marked with a horizontal line. Following this criterion, the dendrogram was trimmed at the linkage height of 6.37, resulting in three homogeneous clusters, which can be characterized as follows:

- Group I (red color) includes articles on various continents, except for Asia. The research results indicate that green credits contribute to the intensification of energy transition and also reduce risk. On the other hand, green bonds support technological innovations in the field of renewable energy, and reduce costs and risk. It is also important that the interest of stakeholders (e.g., banks, city leaders) stimulates growth of the green bond market.
- Group II (blue color) contains articles that discuss two types of relationships. The first concerns the impact of green loans on CO_2 reduction and technological innovations in renewable energy. The second illustrates how green bonds support energy transition financing.
- Group III (green color) includes papers covering companies of various sizes (small, medium, large) that were published in 2024 and later. These include research covering stakeholders, manufacturing/production and service sectors in developed countries in Asia. The articles discuss issues related to brown companies and the impact of green bonds on CO_2 reduction.

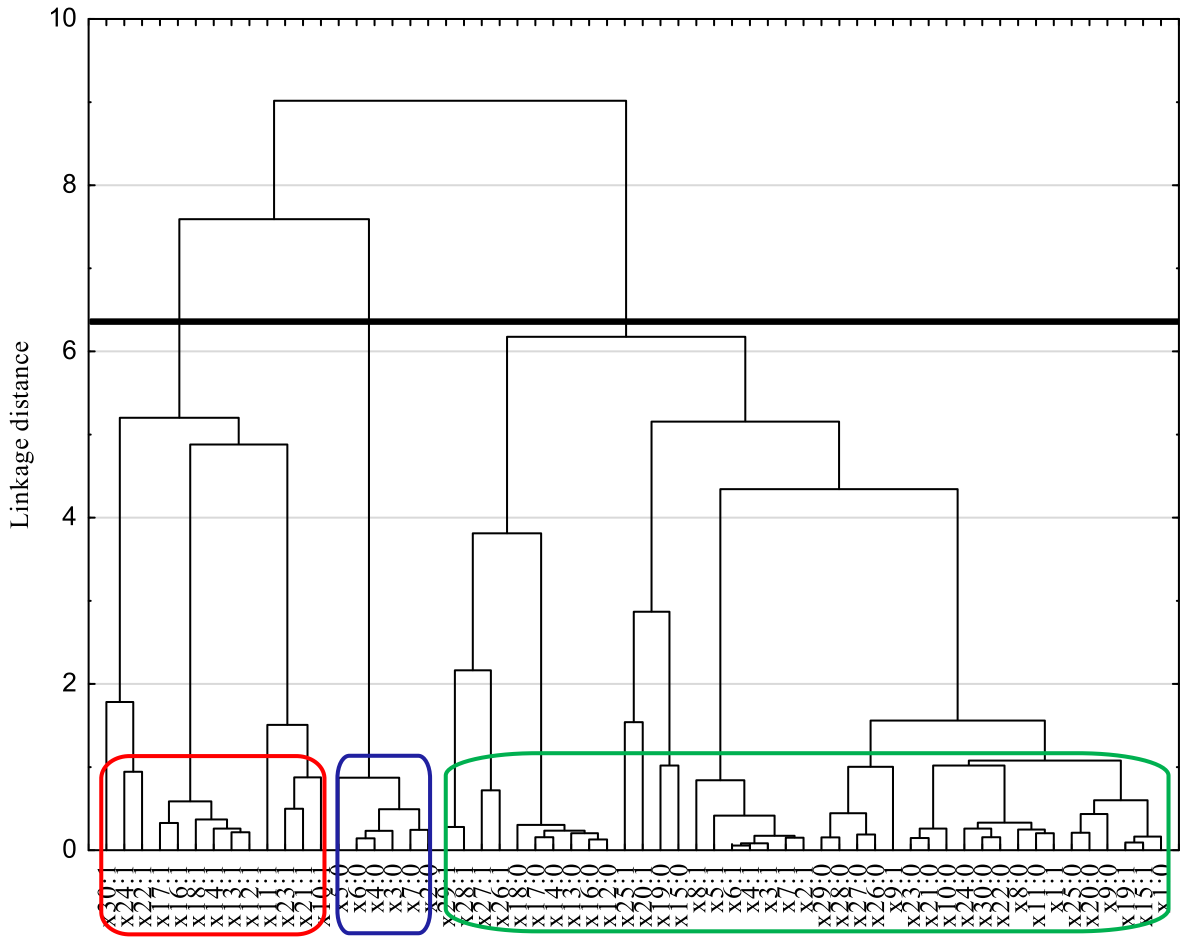

Figure 11. Hierarchical classification diagram of variable categories constructed using Ward's method.

5. Discussion

This study aimed to determine the current state of knowledge—based on a systematic literature review—regarding two key instruments of green finance, green loans and green bonds, with a focus on their involvement in financing the energy transition. To the extent of the authors' knowledge, no studies have been identified in the literature whose findings could be directly compared with the results of this study. However, there are numerous bibliometric analyses focusing on green finance, both in general terms and in relation to specific instruments and their applications in the context of energy transition. An example is the study by Wang et al. [110], who, analyzing 1923 publications from the Web of Science database, demonstrated a significant increase in interest in green finance after 2019, reflected in the growing publication and citation count. Yun and Hu [111], in turn, analyzed the evolution of research over the last decade and identified three dominant research areas: green finance, green investments, and green bonds. They also noted a broadening scope of research, from an academic approach toward practical applications in the industrial sector.

A similar topic was addressed by Mudalige [112], who—based on an analysis of 978 publications from the years 2011–2023 (sourced from Scopus and Web of Science)—identified seven main research trends: (i) the relationship between green finance and environmental sustainability, (ii) green investments, (iii) financial innovations, (iv) policies and regulations related to green loans, (v) the links between green finance and the economy, (vi) the connections between green finance and the concept of corporate social responsibility, and (vii) the challenges, barriers, and level of public awareness in this area.

From a sectoral perspective focused on banking, a study conducted by Yameen et al. [113] analyzed 50 publications published across 35 journals between 1980 and 2022 and identified 22 key factors determining the implementation of green financial practices in banking institutions. The authors emphasized the growing importance of green finance for the functioning of the financial sector.

Green finance is also examined in the context of its impact on business operations, including the energy transition process. Liu and Wu [114], through a literature review, demonstrated a positive correlation between the implementation of green practices and corporate financial performance, while also indicating a negative relationship with the cost of capital. Their study further highlighted the role of green finance in improving risk management and supporting economic development.

The research conducted by Xu et al. [5] also moves toward linking green finance with the energy transition. Based on a bibliometric analysis of 328 articles from the Web of Science database, the authors identified the main research directions in this area using co-citation and keyword co-occurrence analysis. Complementing these findings is the study by Muhmad et al. [115], which reviewed 128 publications from the years 2010 to 2023 and examined the connection between green finance and the growth of renewable energy sources. The authors highlight the significant role of high-impact journals in shaping this research field and the dominant position of China in terms of publication volume. The analysis shows that green finance growth is positively correlated with increased renewable energy investment, emphasizing the need to implement green financing strategies within companies as a key factor supporting an effective energy transition.

The literature also includes analyses focused on specific green finance instruments. A review of studies on green bonds was conducted by Abhilash et al. [116], who analyzed 265 publications from the Scopus database spanning the years 2011–2022. Their findings show a sharp rise in interest in this instrument, with an average annual growth rate of 55.12% in the number of publications. The authors emphasized the key role of green bonds in financing environmentally friendly projects, including investments in renewable energy sources. Similar conclusions were drawn by Cortellini and Panetta [117], who, based on an analysis of 53 publications from the Scopus and Web of Science databases covering the years 2007–2020, not only confirmed the significance of green bonds in supporting environmental initiatives but also identified the main research directions in this area. Woode [118], on the other hand, highlighted substantial geographical disparities in the analyzed literature—studies focusing on Asian and European countries were predominant, while relatively few analyses addressed South America and Africa. The present study partly supports this observation.

An analysis of green loans and bonds was also carried out by Gilchrist et al. [54], who focused on the factors influencing their adoption by companies. Their research indicates that the use of these instruments contributes not only to increased shareholder value but also brings tangible benefits to non-financial stakeholders by supporting the achievement of sustainable development goals.

The importance of green loans and bonds in the context of the energy transition was further confirmed in a study by Wang et al. [110]. Based on a bibliometric analysis, the authors considered variables such as year of publication, company size and sector, geographic origin of the authors, and how these instruments influence the attainment of energy transition objectives.

6. Conclusions

This article is a study of the role of green credit and green bonds in the transformation of the energy market toward renewable energy sources. The article is a review paper, presenting the state of research in the area studied. The study uses a critical review of the literature and correspondence analysis to achieve its intended objective. The study identifies three typological groups of published articles. Group I includes articles from various continents (excluding Asia) showing that green credit plays a role in the intensification of energy transition and reduces investment risk, while green bonds drive technological innovation in the renewable energy sector, reducing costs and risks. It also highlights the importance of stakeholder engagement, such as banks and local governments, in the development of the green bond market. Group II focuses on two types of relationships: first, the impact of green credit on reducing CO_2 emissions and fostering technological innovation in renewable energy; second, the role of green bonds as instruments for financing energy transition. Group III consists of publications from 2024 onward, focusing on enterprises of various sizes located in developed countries in Asia. The innovative approach comes from a holistic view of both the sources of financing and green innovation regarding their importance for the energy market. This study is subject to certain limitations. First, the analysis was conducted exclusively on articles indexed in the Web of Science database, which may have led to the exclusion of research published in regional or non-indexed journals. Furthermore, the inclusion of only English-language publications introduces a potential language bias and may result in the omission of contributions from non-English-speaking regions. Future work assumes an in-depth analysis of texts published in the field of green credit financing, with particular emphasis on the requirements set by financial institutions for financial credibility assessment. Based on the research, implications can be formulated for policymakers, investors, and financial institutions. In particular, governments and public policies should consider implementing policies that encourage the use of green credits or the issuance of bonds through a range of tax incentives or by influencing the price of these instruments to make them more attractive than traditional financing. Fiscal incentives should also support investors in their decisions regarding capital investments in green bonds. It is worth considering the complementary role of green credits and green bonds to design policies combining these two instruments in the financing strategies of enterprises and governments. Financial institutions, in turn, should fully adapt their internal procedures and risk assessment systems to a comprehensive ESG risk management framework, for example, by offering green credits while considering the integration of ESG risk in lending decisions.

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Abbreviations

This manuscript uses the following abbreviations:

OECD	Organisation for Economic Co-operation and Development
RES	Renewable Energy Sources
MCA	Multiple Correspondence Analysis
SDGs	Sustainable Development Goals
IMF	International Monetary Fund
WOS	Web of Science
UNDP	United Nations Development Programme

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