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Review

The Role of Financial Markets in Energy Transitions

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Abstract: This review organizes the current state of knowledge on the role of financial markets in energy transition. The originality of the study lies in the delimitation of its scope and diagnosis of research trends concerning the role of financing, innovation, and financial development sources. The study sets out to identify the role of the financial market in the energy transition process and present the state-of-the-art and main research focuses. For this purpose, a literature review was carried out based on the search results from the Web of Science database and using VOSViewer software, version 1.6.20. The analysis of 54 papers in the final sample allowed us to pinpoint the key links between financial markets and energy transition. Capital markets support green initiatives, with green bonds as a primary funding source. Blockchain and fintech technologies also significantly contribute to transition by offering innovative solutions. Additionally, a range of papers examine the costs associated with energy transition and the role of financial instruments in managing these. Regulatory challenges are another significant focus. This comprehensive analysis underscores the multifaceted relationship between financial markets and energy transition, providing insights into the current trends and the critical role of finance in fostering a sustainable future.

Keywords: green transformation; renewable energy sources; GHG emissions; financial markets; innovation; financial development

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1. Introduction

The impact of non-financial factors (environmental, social, governance), especially environmental, on the economy and society has been the subject of recent discussions and publications on a global scale. Generally, all sectors of the economy are affected by climate change. The negative environmental effects on society and the economy are among the reasons for action being taken by financial and non-financial sector institutions, including governments, to mitigate the impact. Greenhouse gas emissions are one of the drivers of climate change and global warming. Hence, the key issue in reducing climate risk is energy transition, one of the components of green transition of economies. Energy transition requires financing, and the scale of the necessary expenditure is currently one of the greatest challenges at the local and global levels.

The demand for financing is from both the public and the financial markets. Public support programs have already been launched in many countries, but their scope still needs to be expanded depending on the needs. The European Union has adopted many pro-environmental solutions, including the European Green Deal, which lays down a requirement to create financing mechanisms which support the shift in energy sources, mainly by replacing fossil fuels with renewables.

Another area that requires financing is the technological, as well as financial, innovation necessary in the transformation process of energy markets. When observing the

energy and financial markets, one can see the parallel progress of these and their interdependencies. The role of financial markets is crucial in ensuring access to capital, with risk and knowledge transfer to the corporate sector. The literature on financing energy transition and the links between the financial market and the energy market, as well as energy transition as such, is abundant. Many authors have covered these problems from different perspectives.

This paper sets out to identify the role of the financial market in the energy transition process and present the state-of-the-art developments and main research focuses. To organize the state of knowledge and identify the current research trends for the role of financial markets, the following research questions are asked:

1. How do financial markets support energy transition?
2. Do financial innovations accelerate energy transition?
3. Which financial products matter the most in supporting energy transformation?
4. What are the main barriers to financial markets supporting energy transition?

The remainder of this manuscript is organized as follows: Section 2 presents the theoretical framework, primarily the literature review; Section 3 describes the data, methodology, and results; Section 4 provides the discussion; and Section 5 outlines our conclusion.

2. Literature Review

Energy transition is an integral part of the transformation of the economy towards sustainability and is necessary to the achievement of the climate and environmental goals consistent with the European Green Deal and, previously, the 2030 Agenda. There is no single universal definition of the concept of "energy transition", but the terms that have been used in the literature have some common features (Table 1).

Table 1. Definitions of energy transition.

Source	Definition
International Renewable Energy Agency (IRENA)	"a gradual and steady shift of global energy use from fossil-based sources to a zero-carbon system by 2050"
European Parliament (EP) [1]	"a long-term structural change in energy systems aimed at developing a secure, affordable and climate friendly energy system better able to manage and balance dynamic patterns of supply and demand from a national and even European level right down to a local level"
S&P Global [2]	"refers to the global energy sector's shift from fossil-based systems of energy production and consumption—including oil, natural gas and coal—to renewable energy sources like wind and solar, as well as lithium-ion batteries"
Urban Innovative Actions (UIA) [3]	"a shift from a system dominated by finite (chiefly fossil-based) energy towards a system using a majority of renewable energy sources, also maximizing the opportunities available from increased energy efficiency and better management of energy demand"

Energy transition is a process of structural transformation of the energy sector involving the replacement of fossil fuels with renewable energy sources. This process aims not only to reduce the economy's dependence on fossil fuels [4] but also to contribute to climate change mitigation [5] and building a resilient infrastructure [6].

The process of energy transition towards low-emission energy sources is difficult, multidimensional, and individualized for each type of renewable energy. In recent years, many publications have appeared on this issue. Table 2 contains a summary of the main directions of the research which has been undertaken in this area.

Table 2. Main directions of research in the field of renewable energy sources.

Solar energy	Roadmap [7–9]; importance as a source of renewable energy [10]; financial market, financial instrument [11,12]; public policy [13]; barriers [14]; financing [15]; risk [16,17].
Wind energy	Roadmap [8]; importance as a source of renewable energy [18]; financial market, financial instrument [11,12,19]; financing [15]; risk [20,21].
Geothermal energy	Public policy [22]; financing [23–26]; barriers [27,28].
Hydropower	Roadmap [29]; efficiency [30]; risk [31]; barriers [32].
Biomass energy	Efficiency [33]; public policy [33,34]; importance in the transformation process [35]; roadmap [36], barriers (risks) [37,38].

In order to monitor the energy transition process, with the necessary checks and course adjustments, it is necessary to define the energy transition metrics. Due to the complexity of the process itself, a set of indicators is needed, which, due to the fact that the energy sector is the largest emitter of greenhouse gases, are based on sectoral emission factors [39]. Figure 1 shows the energy transition indicators proposed by the International Energy Agency.

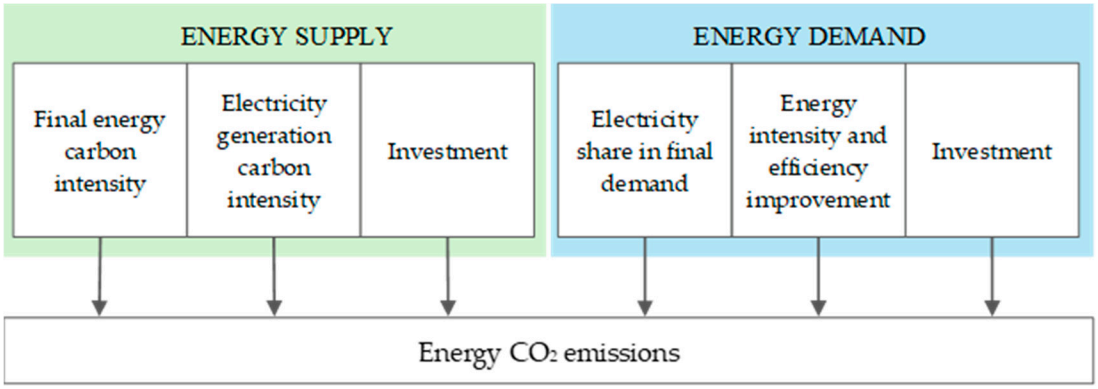

Figure 1. Energy transition indicators.

The following indicators are used to monitor the progress of the process in implementing key elements of the energy system in order to achieve the 1.5 °C scenario [40]:

1. Renewables
   - Renewable Electricity Generation—the proportion of renewables in electricity generation, increases in renewable power capacity, yearly solar PV capacity additions, and the required investments for renewable energy generation, grid upgrades, and flexibility;
   - Renewable Energy in Direct Use and District Heating—the share of renewables in final energy consumption, solar thermal collector area size, use of bioenergy, consumption of geothermal energy, district heating from renewables, and the investments needed for renewable applications in end-use sectors and district heating;
2. Energy efficiency—the rate of energy intensity improvement and the investment needed to enhance energy conservation and efficiency;
3. Electrification—the role of direct electricity in final energy usage, growth in electric passenger vehicles on the road, and the investments required for EV infrastructure and support for EV adoption;
4. Hydrogen—clean hydrogen output, electrolyzer capacity, and the investment needed for developing clean hydrogen infrastructure and related derivatives;
5. Carbon Capture, Utilization, and Storage (CCUS) and Bioenergy with CCUS (BECCS)—emission reduction through CCUS and BECCS, the total emission offset by these technologies, and the investment needed for carbon removal infrastructure.

The process of energy transition towards renewable and low-emission energy sources has encountered many barriers due to its multidimensionality and individuality. According to the World Energy Transition Outlook 2023 report, the main barriers in this area include in-

sufficient infrastructure to connect renewable energy market, skills and institution capacity, and policy and regulations [41].

Macheda [42] pointed to the role of the state in a country's energy transition process. He showed that the state's active participation in the energy sector can accelerate the process of replacing fossil fuels with renewable energy sources and thus contribute to achieving sustainable development goals, e.g., by alleviating household energy poverty [43].

The scope and pace of a country's energy transformation process are determined by the adopted policies and regulatory frameworks at the international, national, and regional levels. Lin et al. [44] showed, based on their research, that adopting a single climate policy has a positive impact on the energy transition process. Lutz et al. [45] proved that it also leads to a reduction in the differences between the energy transition processes of individual regions.

Individual countries define their individual goals when formulating their energy transition policies, although common goals are also visible. Sovacool [46] identified such goals for the Nordic countries. They include promoting decentralized and renewable forms of electricity supply; switching to more sustainable forms of transport; improving the energy efficiency of residential and commercial buildings; and adopting carbon capture and storage technologies for industry.

A major problem in the energy transition process is the still incomplete (i.e., work in progress) regulatory framework, especially for new clean energy options. Do and Burke [47] made recommendations in this regard, such as to revamp regulations to facilitate investments in clean energy, electricity transmission, and energy storage, to continue to prioritize the political decision-making by energy transition criteria, and to build broad support for renewable energy among society and businesses.

Thomas et al. [48] on the example of Italian SMEs demonstrated that small- and medium-sized enterprises are sensitive to energy issues and open to increasing the use of low-emission energy. Sirin et al. [49] emphasized, however, that the process of energy transition of enterprises requires stable macroeconomic conditions. Unfavourable macroeconomic outlook, resulting in a significant increase in liabilities and an increased risk of bankruptcy, may slow down SME investments in the energy sector, despite the availability of state incentives [50].

Frondel et al. [51] pointed to the importance of state financial support in energy transition. The state can support the energy transition of enterprises and households in a number of ways. One of the most commonly used methods are subsidies for the investments related to renewable energy sources. Sokołowski and Bouzarovski [52] emphasized the effectiveness of the Clean Air and My Electricity programs in Poland, under which entities received subsidies for investments in clean heating technologies and small-scale PV installations. These support instruments have brought positive results. Li et al. [53] showed that with subsidies, enterprises lean more to technical innovations towards low emissions.

The cost of energy is an important factor in decisions to switch to renewable energy sources [54]. Although the total costs associated with energy production have decreased, clean energy technologies require large investments to deploy over a long period of time [55]. The problems with financing an energy transition were a point for analysis by the experts from the World Bank Group. Their report "Scaling Up to Phase Down: Financing Energy Transition in Developing Countries" identified the main barriers preventing developing countries from accelerating their energy transition, including the need to incur high initial capital costs and high costs of sourcing capital, which distort the accuracy of investment decisions [56].

Affordability is also one of the main barriers for households to implementing renewable energy solutions. These technologies are not available to low-income households burdened with energy poverty and energy accessibility problems [57,58]. Support programs (availability of subsidies) significantly increase the rates of household transition to renewable energy sources [59].

Enterprises can source for funding for energy transformation from the banking sector or capital markets. Among sources of financing offered by banks, green credit is the most popular. Li et al. [60] proved that green credits promote the green transition of enterprises, especially those that pollute heavily. Zhang et al. [61] reached similar conclusions. Based on a study of 1021 Chinese enterprises listed on the stock exchange in 2007–2017, they demonstrated that the introduction of green credit guidelines stimulated the investments in renewable energy. In turn, Li et al. [53] showed that a subsidy for green credits provided by the government can contribute to improving the quality of the environment by reducing the emissions by enterprises.

Capital markets are becoming an increasingly common source of financing for energy transition. Muhammad et al. [62] proved that, despite their limitations, green bonds have transformative potential. Steady growth, standardization, and innovative applications can further strengthen green bonds as essential instruments for financing global transition towards a low-emission, climate-resilient future. Additionally, the green bonds used to fund renewable energy projects can generate significant returns for investors [63]. Research by Lichtenberger et al. [64] showed that investing in green bonds can protect investors and portfolios from high oil prices and business cycle fluctuations, as well as stabilize portfolio returns and volatility. The growing importance of capital markets in financing an energy transition makes it worthwhile to analyze the state of current research in this area and to highlight possible directions for future research, which is the authors' contribution to science.

3. Methods and Results

In this paper, to indicate the role of the financial market in the energy transition process, a literature review was carried out with the aim of identifying publications that included the following keywords: energy transition; renewable energy sources; sustainability; financial market; financial innovation; financial development; and financial products. For this purpose, the Web of Science (WoS) database was searched, to identify 326 publications from the years 2012–2024. The search included titles, keywords, and abstracts. The initial sample was examined using the VOSviewer software, version 1.6.20. A detailed analysis of the publications with at least seven co-citations allowed for the identification of three clusters containing the selected keywords and their interrelationships (Figure 2). The clusters are as follows:

1. Corporate social responsibility, corporate sustainability, disclosure, eco-innovation, environmental performance, financial markets, financial performance, financial services, financial sustainability, firm, firm performance, firms, governance, green innovation, impact, innovation, management, model, performance, quality, social-responsibility, strategy, sustainability, sustainable development;
2. CO_2 emissions, cointegration, consumption, economic growth, energy consumption, environmental sustainability, financial development, growth, nexus, renewable energy, trade, urbanization;
3. China, determinants, investment, panel data, renewable energy sources.

Notably, all selected keywords were identified in individual clusters, except for energy transition. In the first cluster, the most frequently represented are those related to financial sustainability and innovation, including green innovation. Also interesting are the terms related to financial performance and corporate social responsibility in the cluster. Among the keywords of the second cluster, financial development and renewable energy appear. The third cluster, on the other hand, primarily concerns renewable energy.

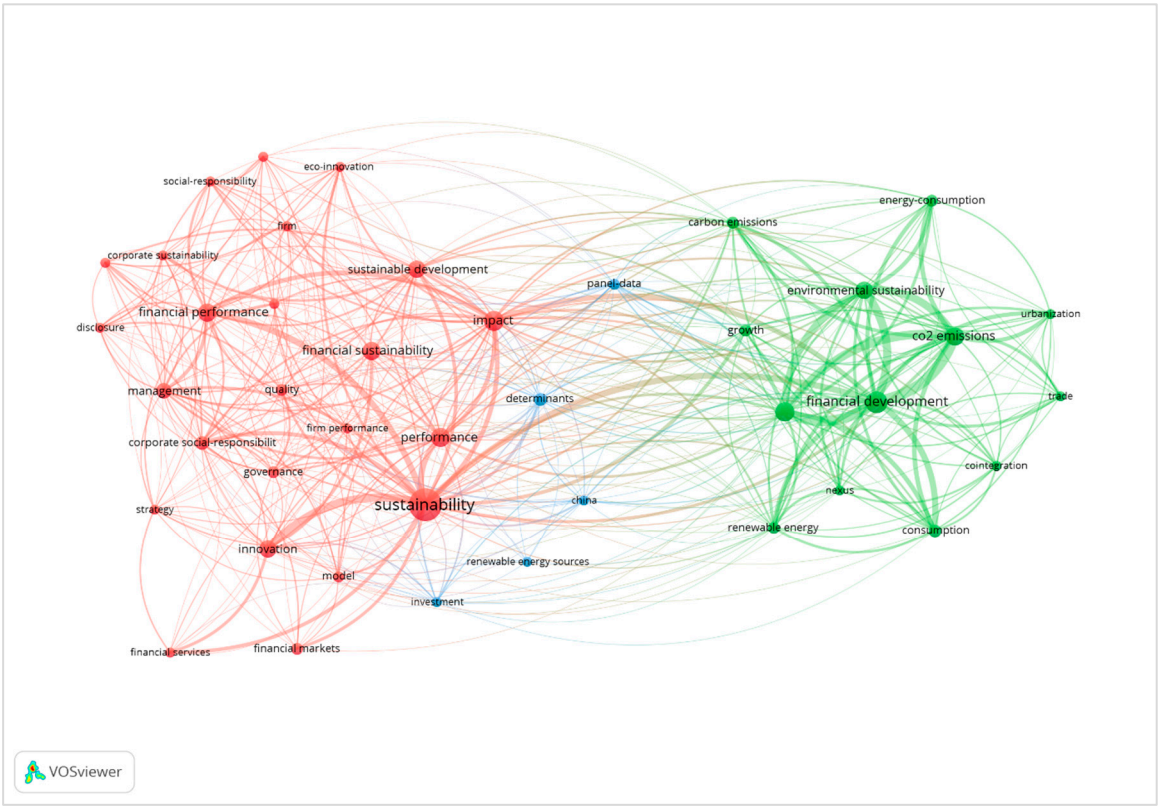

Figure 2. Clusters network.

After a thorough content analysis of the publications from the initial sample, 54 papers were selected for further analysis. Although the selected publications covered the years 2012–2024, only one relevant paper was found from 2012 and no papers from 2013 to 2016 (Figure 3). A total of 7 publications were found from 2017 to 2019, which is equal to the number of papers in 2020, revealing a significant increase in the number of publications in that year. However, a larger increase can be observed in 2023 and 2024, with 15 papers published in each year.

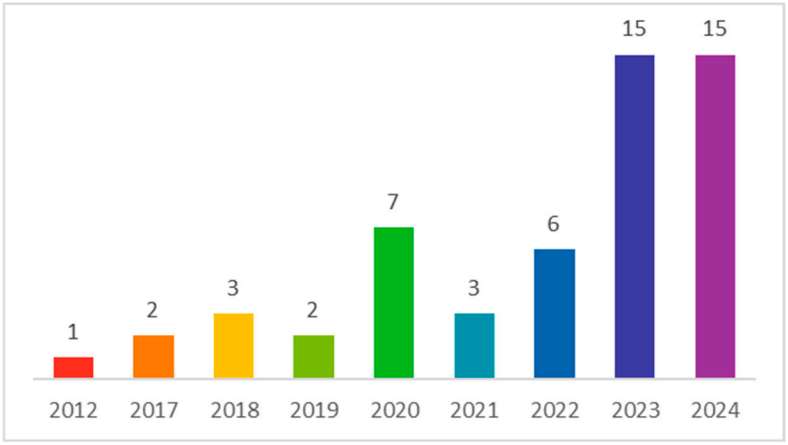

Figure 3. Numbers of publications in particular years.

In the study sample, the largest share (25%) of papers focuses on the Asia and Australia region (Figure 4). Slightly fewer articles (24%) focus on Europe. Interestingly, the next region in terms of the number of publications devoted to is Africa. Papers concerning North America account for the smallest share.

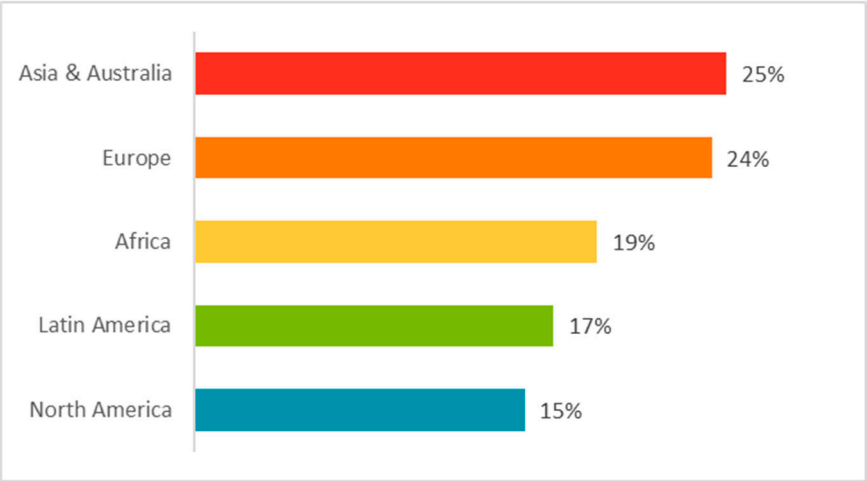

Figure 4. Regions under studies presented in selected publications.

As for the countries covered by the papers, the majority (62%) are developed countries (Figure 5). The smaller number of publications devoted to developing countries indicates a lower interest in issues related to energy transition in these compared with developed countries. This is in line with expectations, as wealthier countries with better developed economies play the leading role in energy transition.

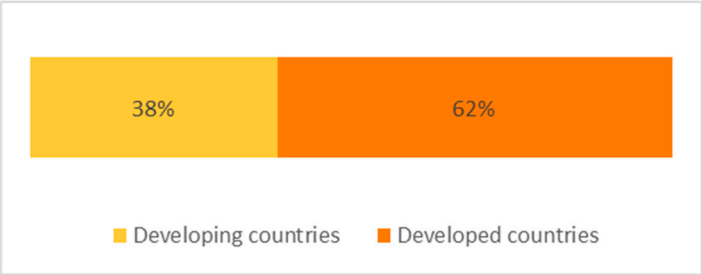

Figure 5. Development of the countries under studies presented in selected publications.

The analysis of the country of origin of the first author (it is often also the country of origin of the co-authors) provided interesting results. The largest number of authors, over 1/3, come from China, and the second place, with an over 2.5 times smaller share, goes to the UK (Figure 6). The third largest group consists of authors from Germany, and the fourth from France. The next three places are for authors from Poland, Saudi Arabia, and South Africa, ex aequo. The dominance of Chinese authors is clear when considering individual countries, but the total share of authors from Europe is slightly higher (42.3%). Nevertheless, as noted earlier, papers on Asia and Australia have the largest share in the study sample of 54 articles. This demonstrates how important and timely the issues related to energy transition are in this region, particularly in China.

The vast majority (71%) of papers presented data-based research (Figure 7). Literature review was the second most common research method (18%), and survey was the least (11%).

The analysis of the papers selected for the study allowed us to pinpoint the links between energy transition and financial markets. These links indicate the existence of multiple relationships among the variables from the energy, environment, and financial categories. A list of the 30 identified relationships relevant to the subject of the study is presented in Table 3.

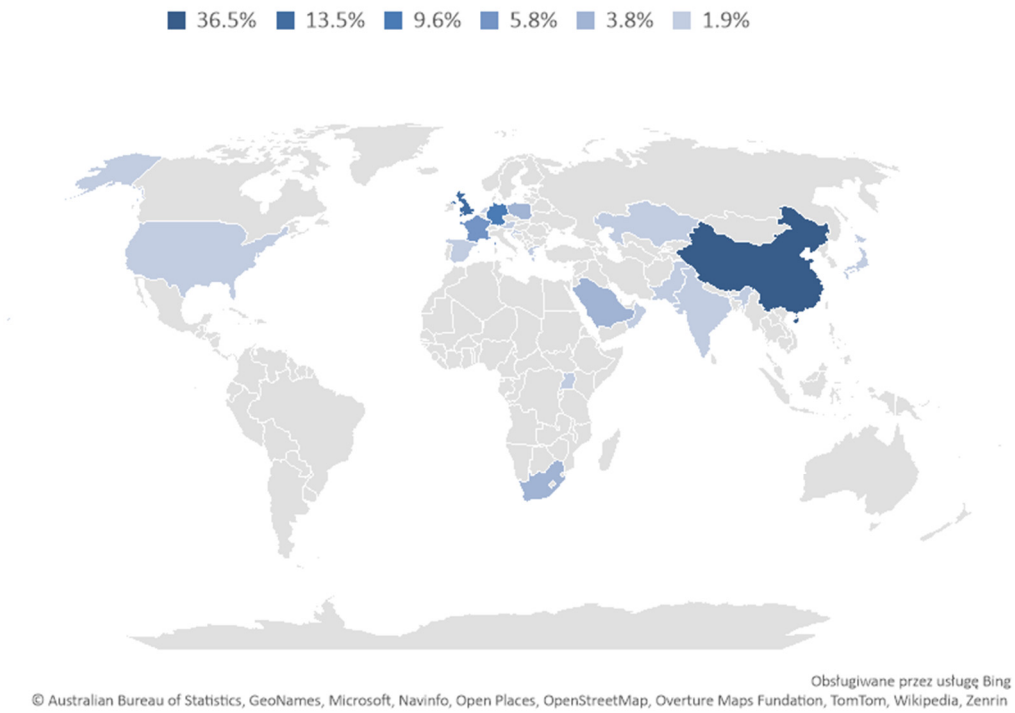

Figure 6. First author's country of origin.

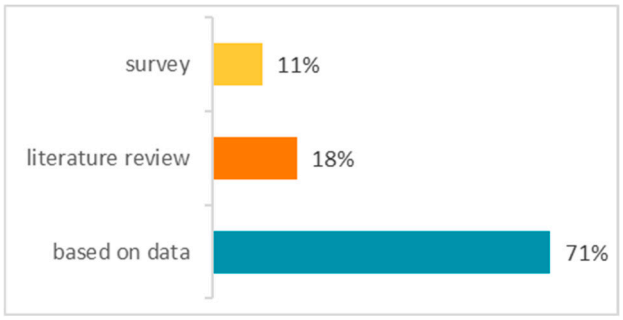

Figure 7. Research methods used in the selected publications.

Among the identified relationships, the most frequently presented is the support of green initiatives by capital markets, which accounts for almost 16% of all dependencies (Figure 8). These initiatives are mainly projects related to renewable energy sources (RESs). The second largest group of papers (11.1%) indicate that green bonds are the main source of financing for energy transition. In the third place, with a slightly smaller share (10.3%), is the impact of blockchain and fintech on energy transition. This impact is positive, indicating that fintech- and blockchain-based solutions support energy transition. The share of papers pointing to the problem of regulatory environment in energy transition is also significant. The most important problem is the lack of appropriate regulations in this area (9.5%). A large part of the papers is devoted to the relationship between financial market instruments and energy transition costs. The positive impact of financial market instruments on reducing transition costs is featured in almost 9% of all the identified relationships. Also notable are the dependencies indicating that financial development supports green energy transition, low availability of financial instruments delays energy transition, and green bonds decrease firms' carbon emissions.

The above-mentioned dependencies ranking in the first eight places in terms of frequency of occurrence in the papers account for almost 70% of all identified relationships. The share of each of the next 10 relationships does not exceed 2.5%. The 12 least frequent dependencies were grouped as "Other" due to their low individual contribution.

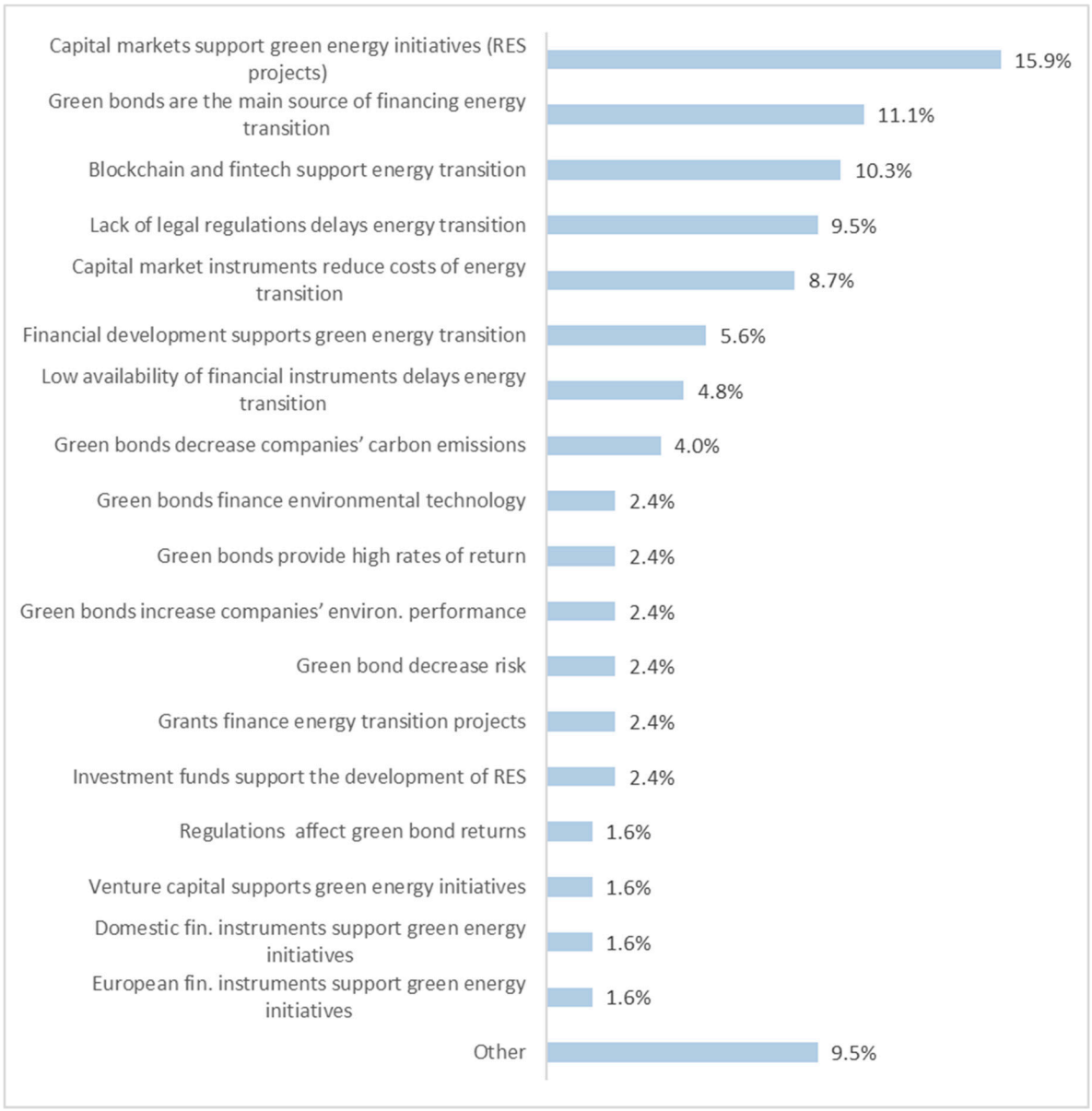

Figure 8. Share of relationships identified in the analyzed publications.

Table 3. Relationships identified in the analyzed publications.

1	Capital markets support green energy initiatives (RES projects)
2	Green bonds are the main source of financing for the energy transition
3	Blockchain and fintech support energy transition
4	Lack of legal regulations delays energy transition
5	Capital market Instruments reduce the cost of energy transition
6	Financial development supports green energy transition
7	Low availability of financial instruments delays energy transition
8	Green bonds decrease companies' carbon emissions
9	Green bonds finance environmental technology
10	Green bonds provide high rates of return
11	Green bonds increase companies' environmental performance
12	Green bond decrease risk
13	Grants finance energy transition projects
14	Investment funds support the development of renewable energy sources
15	Regulations can affect green bond returns

Table 3. *Cont.*

16	Venture capital supports green energy initiatives
17	Domestic financial instruments support green energy initiatives
18	European financial instruments support green energy initiatives
19	Traditional financial institutions support financing of high-emission energy production
20	Banks support financing of high-emission energy production
21	Financial openness supports green energy transition
22	Exchange rate supports green energy
23	Insufficient financial resources are the main obstacles to achieving higher RES adoption rates
24	Private equity supports green energy initiatives
25	Banks are reluctant to finance renewable energy projects, perceiving them as a high risk
26	Banks support financing green energy initiatives
27	Banks support financing of energy transition
28	Green bonds don't give high rates of return
29	Green bonds are sensitive to oil prices
30	Developed capital markets support green energy initiatives

4. Discussion

The aim of this literature review was to identify the main directions of research on the role of financial markets in supporting energy transition. The study was conducted in two stages. In the first stage, the Web of Science database was searched using a set of keywords to obtain a group of relevant scientific papers. The papers were verified in the next stage in terms of alignment of the content with the analyzed aspects. As a result of the verification, a sample of 54 papers were selected. An in-depth analysis of the content revealed a variety of studies related to energy transition. The largest amount of research focused on showing the importance of capital markets in supporting the pursuit of green projects (15.9%) and the use of green bonds as the main source of financing for energy transition (11.1%), the usefulness of blockchain and fintech in the process of transition to low-emission energy sources (10.3%), and the impact of insufficient or missing regulatory framework on slowing down the energy transition process (9.5%).

To the best of the authors' knowledge, no similar study has been conducted. Research on the role of financial markets in energy transformation from the perspective of trends and investment opportunities in renewable energy and clean technologies was conducted by Li [65]. The results of the study indicated that investments in clean technologies and renewable energy have recently significantly increased. Private equity, venture capital, and specialized funds are examples of the participation of financial market entities in energy transformation, in which they played a key role in financing these processes. There has been a change in the way money is invested in the energy industry; investments in fossil fuels are falling, while investments in renewable energy are growing significantly.

Mazzaranno [66] examined how energy transformation impacts financial markets. The study revealed that auction mechanisms impose challenges that businesses are motivated to overcome by lowering emissions. However, the research highlighted that reductions in greenhouse gas emissions positively influence TQ only when they lead to improvements in energy efficiency.

A review of the financial mechanisms of energy transformation was conducted by Long et al. [67]. The research showed that the framework of the financial mechanisms of energy transformation is made up of public financing mechanisms, private financing mechanisms, market-based mechanisms, innovative financing mechanisms, risk mitigation instruments, and institutional support and capacity building. A review of the incentives and financing strategies for energy transformation was conducted by Qadir et al. [14]. The research showed that financing is the main obstacle to the implementation of energy transformation. Although financing policies and strategies are already in place, the involvement of financial institutions in providing support to society to invest in RES in the form of, for example, soft loans or the creation and facilitation of crowdfunding and crowdsourcing platforms can accelerate and enhance this process.

A literature review using a similar methodology was carried out by Genc and Kosempel [68]. Based on keywords related to renewable energy sources and environmental pollution, they

identified 875 papers in the WoS database published in 2017–2022. They focused on publications with the highest citation rate (31) and papers published in *Energies* (58). The researchers identified the following most common directions of research: wind capacity and energy pricing; wind energy and emissions reduction; value estimation of intermittent solar energy; cross-border trade in electricity from both conventional and renewable sources along with its environmental impact; and the influence of renewable energy ownership on prices and emissions.

Based on the articles found in the WoS database (4960), Xu et al. [69] reviewed the state of research on the diffusion of green supply chain management in the context of energy transition. Their analysis revealed that research on energy transition technologies within the supply chain is limited, making it a valuable exercise to explore the technical measures that can reduce energy consumption across the entire chain—from product design to raw material procurement, production, transportation, warehousing, recycling, and remanufacturing. Additionally, with numerous energy restriction policies in place, examining the ways to enhance the effectiveness of these policies is another important area for further research. Finally, there is a shortage of studies on the role of the green supply chain in promoting energy transition in enterprises.

Kozar and Sulich [70] conducted a bibliometric study of scientific publications indexed in the Scopus database, the aim of which was to examine the areas of transformation of the green energy sector in the context of achieving the sustainable development goals. The analysis of bibliometric maps, similarly to our study, showed that green transition in the energy sector is multifaceted, and that many papers have addressed the topic of the energy transition but few have focused on the transition process itself.

5. Conclusions

This paper addresses the critical issue of financing energy transition in the context of climate change and the risk of non-financial factors. It reviews the literature published in this research area. It also shows the main research lines, the countries of origin of the researchers, and the extent and significance of the impact that financial markets have on the energy transition process.

This paper sets out to quantify the role of the financial market in the energy transition process and to present the state-of-the-art and main research focuses. A literature review was carried out with the aim of identifying the essential publications. For this purpose, the Web of Science (WoS) database was used, and 326 publications from 2012 to 2024 were selected. The search included titles, keywords, and abstracts. The initial sample was examined using the VOSviewer software. After a thorough content analysis, 54 publications were selected for further study. Although the selected papers covered the years 2012–2024, only one relevant publication was found from 2012, and no publications from 2013 to 2016. A total of seven publications were found from 2017 to 2019. The articles selected for the study allowed us to find the links between energy transition and financial markets. These links indicated the existence of multiple relationships. Among the identified relationships, the most frequently presented were the support of green initiatives by capital markets; green bonds as the primary source of financing for energy transition, and the impact of blockchain and fintech on energy transition; the problem of regulatory frameworks related to energy transition; and the relationship between financial market instruments and energy transition costs.

Based on the literature review conducted in the context of the research questions posed, it was found that the largest share (25%) of articles focused on the Asia and Australia region, and the smallest was linked to North America. The vast majority of publications concerned developed countries, and most of the authors of the publications came from China and the UK, followed by authors from Germany and France. When analysing the main research lines considered in the papers, one should pay attention to the green bond market and green bonds, which are not only a popular source of financing for energy transition but also yield a positive effect of using green bonds through a reduction in carbon emissions. In turn,

the factors inhibiting the transition processes include insufficient or missing regulatory frameworks and low access to financial instruments. Another critical conclusion of the study is that transition costs can be limited through capital market instruments. The study provides new knowledge, which is particularly useful for the decision-makers responsible for shaping the development policy for energy markets and financial markets. Identifying the interdependencies between these markets and the role of the individual financing tools, with the dominant role of green bonds, is crucial to ensuring the support for energy transformation from governments and financial decision-makers. In this context, there is an urgent need to remove regulatory gaps and the formal and legal constraints of the transition process. We intend to focus future research on a deep dive into the role and mechanism of supporting energy transition using green bonds.

Some corresponding suggestions and policy insights may be formulated based on the research results. Firstly, we demonstrated the significant role of capital markets in financing green transition in the green bond mechanism. This means that governments, financial markets bodies, and regulators should create a space for developing capital markets in their countries. Some mechanisms of tax policies are important in this case, for example, tax reliefs. Also, the system and mechanism of capital markets should be as transparent and easy to use as possible. In this case, regulations on non-financial reporting or ESG reporting, especially on how such reports are organized and how they work, are significant. Secondly, the banking sector may be addressed as banks provide the financial innovations that are, as we have pointed out, the drivers of green transition. Finally, cooperation and networking are essential between the public and private sector actors, and some policies, like governance policies, are crucial.

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Conflicts of Interest: The authors declare no conflicts of interest.

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