Strielkowski, Wadim

Article

Innovations in the energy sector as a powerful catalyst for financial transformations

Marketing i menedžment innovacij

Marketing and Management of Innovations, 15(1), 2024

Innovations in the Energy Sector as a Powerful Catalyst for Financial Transformations

Wadim Strielkowski [1,2,*]

[1] University of California, Berkeley, USA
[2] Czech University of Life Sciences, Prague, Czech Republic
[*] Corresponding author: strielkowski@berkeley.edu

Type of manuscript: Research paper

Cite as: Strielkowski, W. (2024). Innovations in the Energy Sector as a Powerful Catalyst for Financial Transformations. *Marketing and Management of Innovations*, *15*(1), 131–142. https://doi.org/10.21272/mmi.2024.1-11

Received: 10 October 2023
Revised: 16 February 2024
Accepted: 13 March 2024

Publisher & Founder: Sumy State University

Abstract: Conventional wisdom often posits that financial innovations are the primary drivers of energy transitions, facilitating the shift from traditional fossil fuels to renewable sources. However, a nuanced examination of this relationship suggests a reciprocal dynamic where innovations in the energy sector can significantly propel financial transformations. The global pivot towards renewable energy sources necessitates substantial financial investments, thus catalyzing the emergence of novel financial instruments, green bonds, and innovative financing models dedicated to supporting the renewable energy sector. This interdependence between energy transitions and financial innovation reflects the adaptability of financial institutions to the evolving demands of sustainable energy initiatives. As societies increasingly embrace cleaner energy solutions, the financial sector responds by devising inventive strategies to underwrite these transitions. Highlighting the growing academic interest in this symbiotic relationship, the number of publications on energy transitions and financial innovations indexed in the Web of Science database has witnessed a remarkable increase from a mere 10 in 2015 to 113 in 2023, indicating a rapidly increasing field of academic research. This paper presents a comprehensive bibliometric analysis of the existing research literature on the interplay between energy transition and financial innovations. Utilizing a network analysis approach and the VOSviewer software - a tool renowned for its efficacy in uncovering prevailing trends and patterns in interdisciplinary research - the study aims to map out the intellectual landscape of this domain. Our findings elucidate that energy transitions do not merely benefit from financial innovations but can also act as potent drivers of financial change, as evidenced by numerous recent and historical examples. This reciprocal influence underscores the critical role of energy sector advancements in shaping financial practices and instruments. The study's insights contribute significantly to the understanding of how energy transitions and financial innovations mutually reinforce each other, providing valuable implications for policymakers, investors, and researchers focused on fostering sustainable energy ecosystems and financial market resilience.

Keywords: energy innovations; sustainable development; renewable energy; green finance; financial innovations.

Funding: There is no funding for this research.

Acknowledgement: The author acknowledges the inspiration stemming from Dr. Juergen Braunstein of Vienna University of Economics and Business and his ERC-funded "ENFIN" project in completing this paper (keep climbing the mountain). The usual disclaimer applies.

1. Introduction. Innovations in the energy sector are likely to cause substantial transitions in the financial sector, as many examples from recent and modern history show (see, e.g., Polzin & Sanders, 2020; Strielkowski, 2024). The mechanism by which innovations in the energy sector can induce financial transformations can be best explained using the case of green energy (Jiang et al., 2020; Usman & Hammar, 2021; Afshan et al., 2022). Green finance encompasses investments directed towards environmentally sustainable projects, prominently featuring renewable energy initiatives (Sinha et al., 2023; Udeagha & Ngepah, 2023). As nations prioritize eco-friendly energy sources, financial markets respond with specialized products. Green bonds, carbon trading mechanisms, and sustainable investment portfolios emerge, reshaping the financial landscape (Cortellini & Panetta, 2021; Ng et al., 2021). This financial adaptation, in turn, fuels further energy transitions, creating a reinforcing cycle. In turn, government policies incentivize investments in renewable energy, offering tax benefits, subsidies, and favourable lending terms (Qadir et al., 2021). These policies serve as catalysts for financial institutions to channel funds into green projects (Taghizadeh-Hesary & Yoshino, 2020). Simultaneously, stricter environmental standards prompt companies to seek financial resources for energy-efficient upgrades, fostering financial innovations geared towards sustainability (JI & Zhang, 2023). In general terms, technological advancements tend to underpin both energy transitions and financial innovations (Onifade & Alola, 2022). Breakthroughs in renewable energy technologies reduce production costs, enhancing the feasibility of clean energy projects (Ostergaard et al., 2020). In turn, advancements in financial technology (fintech) facilitate efficient investment, risk assessment, and fund management. Fintech solutions enable the creation of innovative financial instruments, promoting investments in renewable energy sources (Croutzet & Dabbous, 2021; Liu et al., 2022).

This paper describes how innovations in the energy sector can become powerful catalysts for financial transformations and how this is reflected in the recent and relevant research literature. Bibliometric network analysis of the documents related to energy transitions and financial transformations from the Web of Science (WoS) database was performed using the Google Trends tool and VOSviewer v.1.6.15 software to study this interdependence and provide meaningful results and conclusions.

2. Literature Review. The link between energy transitions and financial transitions is a fascinating and complex subject (Saadaoui & Chtourou, 2023; Zeraibi et al., 2023). At its core, this relationship highlights how shifts in energy paradigms drive financial innovation and how financial developments, in turn, enable further energy shifts (see, for example, the European Research Council-funded ENFIN project (ENFIN, 2023)). One way of another, as seen from the historical perspective, Amsterdam in the 18th century, London in the early 19th century, or New York in the early 20th century, all constituted major financial centers that thrived in environments where energy transitions were underway (Cassis, 2010; Strielkowski, 2024).

In general, the transition of the energy sector in recent human history has followed a single pattern, from renewable energy, which dominated the world before the 1st Industrial Revolution, through the period dominated by fossil fuels and back to renewable energy in recent decades (Strielkowski, 2021; Seibert & Rees, 2022). Figure 1 presents this path in graphical form.

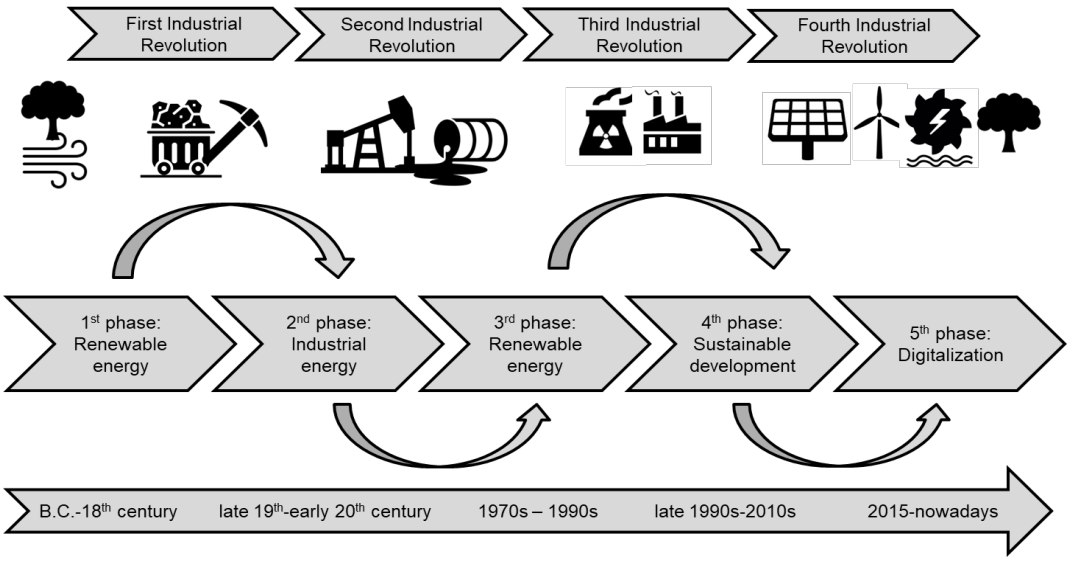

Figure 1. Transition of the energy sector: from renewable energy back to renewable energy
Sources: developed by the author based on (Strielkowski et al., 2021; Strielkowski, 2024).

In the 18th century, Amsterdam was a hub for financial innovation, partly due to its role in global trade and the energy demands that trade created (Accominotti & Ugolini, 2020). As the power of wind and water began to be supplemented and then replaced by coal and other fossil fuels, new financial instruments and institutions emerged to fund the infrastructure and trade associated with these energy sources. The Amsterdam Stock Exchange, one of the world's first, provided a platform for investments in voyages and trade, fuelling the city's prosperity (Miller, 2012). The transition from wood to coal in late 18th and early 19th century Britain constituted an important moment in the country's financial development, as well as a milestone in the world's financial history. At the beginning of the 1st Industrial Revolution, industries, cities, and the whole structure of the British economy experienced profound changes fostered by this energy transition from wood to coal (Barca, 2011). This, in turn, led to substantial economic changes (Moe, 2010). The London Stock Exchange, founded in 1801, became the key institution for new forms of securities, bonds and debentures, which were used to finance public works and industrial ventures, and insurance companies began offering coverage for new and expanding enterprises (Taylor, 2021). Similarly, in early 20th century New York, the transition to fossil fuels such as coal and oil coincided with a massive expansion of the city's financial sector (Kennedy, 2023). Wall Street grew in importance, funding the infrastructure needed for these new energy sources, from railroads for coal transport to pipelines and refineries for oil. This era saw the rise of modern financial instruments and institutions that are still with us today.

In the contemporary world, a similar dynamic is unfolding with the transition from fossil fuels to renewable energy sources (Kalair et al., 2021). This shift requires immense capital for the research, development, and deployment of new technologies (Hassan et al., 2024). As a result, financial markets are innovating to meet these needs. Green bonds, which are used to fund environmentally friendly projects, are a prime example. First issued in 2007, green bonds have grown exponentially as investors seek to fund renewable energy and other sustainable initiatives (Bhutta et al., 2022). Carbon trading mechanisms are another type of financial innovation driven by energy transitions. By putting a price on carbon emissions, these schemes create a market for reducing greenhouse gases, encouraging investment in cleaner technologies (Semieniuk et al., 2021). For example, the European Union's Emissions Trading System is the largest such scheme, and its success has inspired others around the world (Verde & Borghesi, 2022). The rise of sustainable investment portfolios is yet another aspect of this financial transition. Investors are increasingly looking to fund companies and projects that are not only financially sound but also environmentally responsible (Dunz et al., 2021). This shift is changing the calculus for companies as they realize that sustainability can drive investment and growth (Rzayeva et al., 2021; Sciarelli et al., 2021). However, this relationship is not unidirectional. Just as energy transitions drive financial innovation, so too do financial transitions to enable further energy shifts. The availability of new financing mechanisms makes it easier for companies and governments to invest in renewable energy (Wang et al., 2022). As these investments pay off, they demonstrate the viability of renewables, encouraging further investment and innovation.

This reinforcing cycle can be seen in the decreasing costs of renewable technologies such as solar and wind power. As more money has flowed into these sectors, economies of scale and technological improvements have driven costs down, making renewables increasingly competitive with fossil fuels (Luderer et al., 2022). This, in turn, attracts more investment, driving costs down further and accelerating the energy transition. However, many challenges still remain. The scale of the investment needed for a global transition to renewables is immense (Bogdanov et al., 2021). At the same time, traditional financial institutions are often conservative, preferring to invest in known quantities such as fossil fuels (Sunio et al., 2021). Overcoming these hurdles requires not only financial innovation but also policy interventions, such as carbon pricing and renewable energy subsidies. Moreover, the transition must be just and equitable. Historically, energy and financial transitions have often benefited wealthy people at the expense of poor and marginalized people. Today, there is a growing recognition that the shift to renewables must be done in a way that is fair and inclusive, providing benefits and opportunities to all.

3. Financial implications of energy transition and innovation. Energy transitions, referring to the shift from conventional fossil fuels to renewable and sustainable energy sources, have profound financial implications that can significantly impact the economy (Cantarero, 2020). There are multiple implications, challenges, and opportunities that arise during this transformative process. One of the most significant financial implications of energy transitions is the initial investment required to establish renewable energy infrastructure (Hoicka et al., 2021). While fossil fuel-based power plants have been established for decades, renewable energy technologies often require substantial upfront capital investments. These investments

include installing solar panels, wind turbines, or building hydropower plants. However, despite these initial costs, renewable energy sources tend to have lower operational expenses than fossil fuels over their lifespan.

Moreover, transitioning to renewable energy has multiple economic benefits that outweigh these initial costs. It creates job opportunities throughout various sectors, such as manufacturing and the installation of clean energy technologies (Kuzmin et al., 2023). The International Renewable Energy Agency estimates that by 2050, transitioning towards a sustainable energy system could create more than 40 million jobs globally (IRENA, 2020). Another financial implication of energy transitions is their potential impact on traditional fossil fuel industries. As renewable sources become more competitive and widely adopted, there may be a decline in demand for oil, coal, and natural gas (Le Billon & Kristoffersen, 2020). This shift could lead to significant disruptions within these industries and potentially result in job losses for those employed in them.

However, it is essential to note that while some sectors may experience declines during this transition period, others will flourish. For instance, as more electric vehicles enter the market due to the increased adoption of renewables in transportation systems, electric vehicle manufacturing and charging infrastructure development will likely experience an increase in demand (Muratori et al., 2021; Hezam et al., 2022). Furthermore, transitioning towards sustainable forms of energy can reduce the dependence on imported fossil fuels for countries without domestic reserves. This reduction can lead to improved trade balances as less money is spent on importing oil or gas.

The financial implications extend beyond direct investments and industry shifts. Energy transitions can also affect financial markets, as investors increasingly prioritize sustainable and environmentally friendly projects (Du et al., 2023). The growing awareness of climate change and the need to mitigate its effects have led to an increased demand for green bonds and other socially responsible investment opportunities. This shift in investor preferences towards renewable energy projects has the potential to reshape financial markets, encouraging sustainable economic growth (Hailiang et al., 2023).

Innovation in clean energy technologies, such as solar panels, wind turbines, and energy storage systems, has significantly reduced costs while increasing efficiency. This has not only made renewable energy more accessible but also created new investment opportunities in the green economy. Moreover, innovation and technology have played a crucial role in developing smart grid systems (Tan et al., 2021). These advanced digital networks enable efficient electricity transmission and distribution while optimizing energy consumption. By integrating renewable energy sources with intelligent monitoring systems, grid operators can effectively manage supply–demand imbalances and reduce overall energy waste. This enhances financial sustainability by reducing operational costs for both consumers and providers. Furthermore, digitalization has revolutionized the way we consume energy through advancements such as smart meters and home automation systems. These technologies enable real-time monitoring of energy usage patterns, allowing consumers to make informed decisions about their consumption habits, leading to smart grids in the future (Strielkowski, 2019). Furthermore, by promoting greater efficiency at the individual level, these innovations contribute to reducing overall demand for fossil fuels while driving financial savings for households.

One of the primary ways in which the financial sector contributes to a greener future is through investments in renewable energy. Renewable energy projects require substantial upfront capital investment, which can often be a barrier to their development (Sadiq et al., 2022). However, banks, private equity firms, and other financial institutions are now actively providing funding for these projects. They recognize that investing in renewable energy not only helps combat climate change but also offers attractive long-term returns (Li et al., 2021). The shift towards investing in renewables reflects changing attitudes within the financial sector. In the past, there was skepticism about the profitability and scalability of renewable energy projects. However, advancements in technology have significantly reduced the costs associated with solar panels, wind turbines, and other clean energy technologies. This has made renewables more economically viable than ever before (Osman et al., 2023). Furthermore, governments worldwide are implementing policies that incentivize investment in renewable energy. These policies range from tax credits and subsidies to feed-in tariffs and green bonds. Financial institutions are taking advantage of these incentives by directing their capital towards renewables (Vakulchuk et al., 2023). In addition to direct investments, financial institutions are also developing innovative financing mechanisms for renewables. For example, the abovementioned green bonds have gained popularity as effective tools for raising funds specifically for environmentally friendly projects such as solar farms or wind parks. These bonds allow investors to support clean energy initiatives while earning stable returns on their investments. Moreover, some banks have established specialized divisions or departments dedicated solely to sustainable finance or environmental risk management. These divisions focus on integrating environmental, social, and governance (ESG) considerations into investment decisions. By

incorporating ESG factors, financial institutions can identify and mitigate potential risks associated with climate change and environmental degradation (Grijalvo & García-Wang, 2023). Therefore, the evolving role of the financial sector in supporting renewable energy is driven not only by a desire to combat climate change but also by economic opportunities. The renewable energy industry has experienced rapid growth in recent years and is expected to continue expanding. Financial institutions recognize the potential for substantial returns on investments in clean energy projects.

4. Methodology and research methods. The main aim and focus of this paper is to analyse whether innovations in the energy sector can be a powerful catalyst for financial transformations and lead to financial innovations that in turn foster economic and social development. To do so, this paper uses bibliometric network analysis with VOSviewer v.1.6.15 software. This software is often used by academics and researchers for similar bibliometric data overviews and in-depth assessments (Strielkowski et al., 2022).

Figure 2 provides a graphical overview of the bibliometric data collection and analysis used in this paper in the form of a comprehensive diagram of the research phenomenon definition through the choice of the research publication database, criteria definition and limitations to the data extraction, analysis of results and determination of the main conclusions and implications.

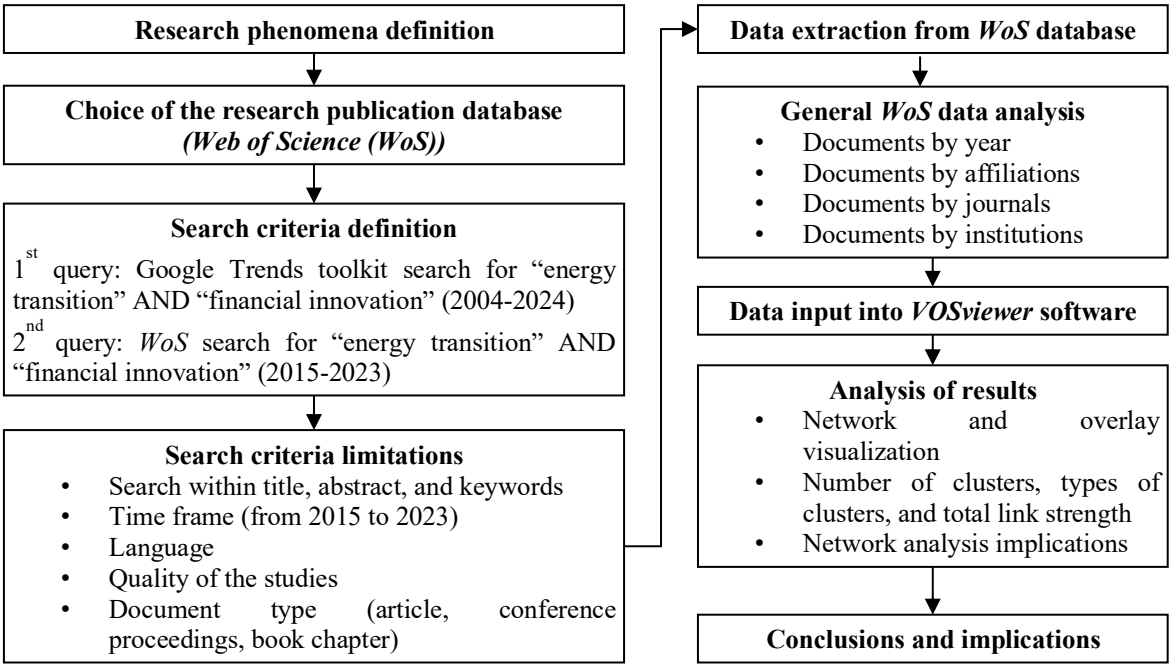

Figure 2. Overview of the bibliometric data collection and analysis.
Source: Developed by the author.

Furthermore, Figure 3, which is shown below, presents the results of the analytical scanning based on the Google Trends toolkit (which is popular with researchers analysing online word searches), showing the frequency dynamics of the worldwide search requests for such terms as "energy transition" and "financial innovation" from 2004 (the first year when the Google Trends data are available) until 2024. It features the so-called "Interest over Time" (IoT) metric, which assesses the search interest relative to the highest point on the chart for the given region and time (with 100 being the peak popularity and 0 showing that no data were available for the given region and time period). Figure 3 clearly shows the interest and focus on both terms as well as the three main periods of their interactions according to the interest over time metrics. The first period, which lasted from 2004 until 2010, was marked by the close entanglement of the Google online search interest of "energy transition" and "financial innovation". The second period, from 2010 until 2016, is marked by increasing interest in online searches for "energy transition". The third period, from 2016 until 2024, is marked by further increasing interest in the search for "energy transition", while the search for "financial innovation" remains at the same steady level. In total, we obtained 385 documents indexed in the WoS Core Collection. There was a notable increase from 10 documents in 2015 to 113 documents in 2023, indicating a tenfold increase. In terms of the publishing outlets that featured the documents covering the topics within the scope of this study for the last 8 years, the top 5 journals list were as follows: 26 documents published in Energy

Research and Social Sciences (Elsevier), 24 documents published in Sustainability (MDPI), 23 documents published in Environmental Science and Pollution Research (Springer Nature), 22 documents published in Energy Policy (Elsevier), and 21 documents published in Energies (MDPI).

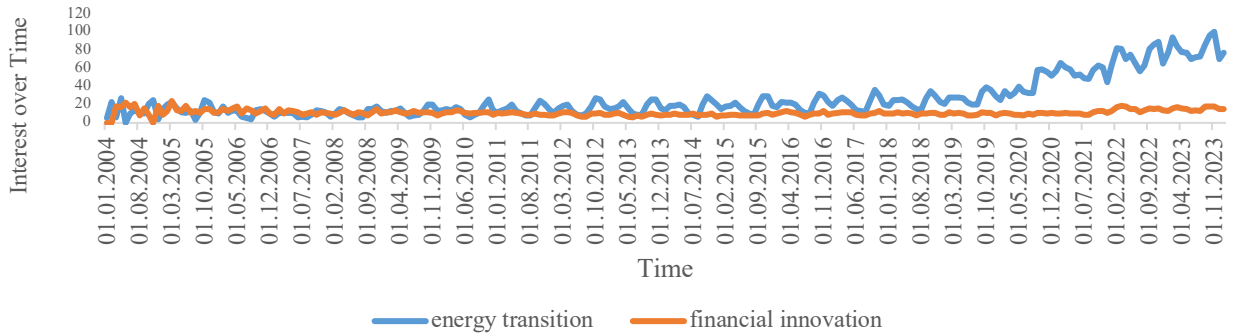

Figure 3. Worldwide online search using the Google search engine using the keywords "energy transition" and "financial innovation" (2004-2024)
Sources: developed by the author based on Google Trends data.

These results indicate that interest in the links between the energy transition and financial innovation has attracted the attention of both large players in the international publishing market (Elsevier) and newcomers (such as MDPI). Furthermore, the results reveal that the topic in question was mostly pursued by researchers from the following universities and research institutions (according to the top 5 affiliations): 15 documents authored or co-authored by the University of Sussex, 13 documents authored by the University of London, 13 documents authored by Utrecht University, 8 documents authored by the University of Groningen, and 7 documents authored by the Imperial College London. The spread of the affiliations indicates that there is serious research interest in this topic, with academics from the most prominent world's universities pursuing it in the course of their respective research agendas.

5. Results. In a co-occurrence network map analysis, each node represents a term or keyword, and the lines (or edges) between them indicate that these terms are often mentioned together in the same publications. The size of the nodes often reflects the frequency of the term's occurrence, and the thickness of the lines between the nodes usually indicates the strength of the relationship (the thicker the line is, the more often the terms cooccur). Our results presented in Figure 4 below reveal four main clusters with interconnecting lines, suggesting a high level of interdependence between the terms in question. This indicates that discussions around "energy transition" and "financial innovation" are not isolated but are interconnected with various other factors, such as "green finance", "economic growth", "environmental sustainability", and "carbon emissions". Those terms that appear larger and more central in our analysis, such as "financial innovation", "nergy transition", "environment", "sustainability", and "green finance", are likely the most prevalent concepts within the literature and may act as hubs within the network. They are likely the main focus of the research body. The terms that are closely connected and central to the map suggest key themes and outcomes discussed in the literature. For example, the close connection between "energy transition" and "financial innovation" and between "environmental sustainability" and "economic growth" suggests that there is a significant focus on how financial innovation can facilitate the transition to more sustainable energy practices, which in turn can influence economic growth.

The analysis of the four main clusters reveals the following results: Cluster 1 (green cluster) appears to focus on the financial aspects of the energy transition, with terms such as "green finance", "financial market", "financial institution", and "financial system". The prominence of these terms suggests that the publications in this cluster are concerned with how financial systems and markets are adapting to or facilitating the transition to renewable energy. The strong connection to "opportunity" and "challenge" indicates a discussion of the potential benefits and obstacles within the financial sector regarding green initiatives. Cluster 2 (red cluster) is centred around terms such as "firm", "process", "production", and "financial support"; this cluster likely addresses the practical application of financial innovation in businesses and their production processes. The cluster suggests an emphasis on how companies finance the transition to energy-efficient processes and the role of financial support mechanisms (such as subsidies or incentives) in promoting sustainable production methods.

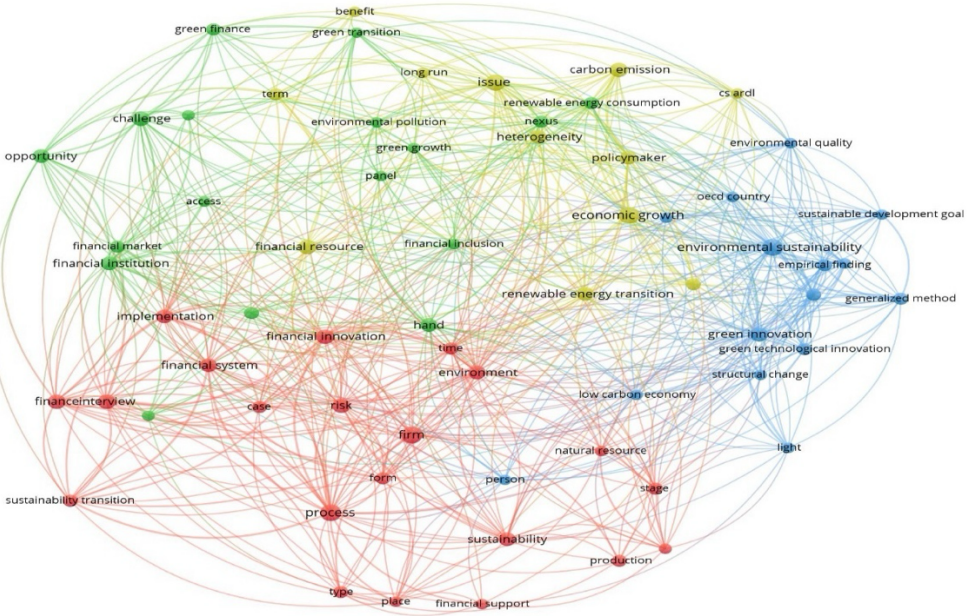

Figure 4. Co-occurrence map based on the text data of the 385 publications containing the keywords "energy transition" and "financial innovation" retrieved from the WoS database
Sources: developed by the author based on VOSViewer v.1.6.15 software.

Cluster 3 (blue cluster) includes terms such as "renewable energy transition", "economic growth", "environmental sustainability", and "low carbon economy". It likely represents literature that discusses the macroeconomic and environmental impacts of the transition to renewable energy, including its effects on economic growth and sustainability. The presence of "OECD countries" and "sustainable development goals" suggests a focus on policy and international development targets related to these themes.

Cluster 4 (yellow cluster) appears to be more technical or methodological, with terms such as "empirical finding", "generalized method", "renewable energy consumption", and "carbon emission". The research in this cluster might be focused on the empirical analysis of energy consumption patterns, carbon emissions, and the effectiveness of various methods or models used to study the transition to renewable energy. The presence of terms such as "policy maker", "OECD country", and "sustainable development goal" suggests that the research is also connected to practical policy considerations and the broader goals set by international bodies. From the network map, it appears that the body of research is quite interconnected, with financial considerations being central to discussions of energy transition. This research is likely multidisciplinary, involving environmental science, economics, and perhaps political science, given the implications for policy and financial systems.

Figure 5 below shows a bibliographic map based on the bibliometric data (coauthorship, keyword co-occurrence, citation, biblio-graphic coupling, or cocitation map). The results depicted in Figure 5 suggest an emphasis on developed countries and their impact on the environment, as well as the role of innovation in reducing this footprint. In addition, there might be broader aspects of transitioning to renewable energy sources, including policy implications and sustainability considerations. The prominence of China within the results suggests a significant focus on the energy policies and transitions occurring in that country, which is a major player in global energy markets. Additionally, there is an apparent focus on the effects of energy consumption and the resulting carbon emissions. Research on how consumption patterns affect emissions and the overall impact on the environment could be highlighted. Finally, the technical and financial aspects of the energy transition also appear to be relevant. The results stress the importance of new technologies such as blockchain as well as the processes of digitalization that influence green finance and the challenges they present. This is quite understandable in light of the significance of fintech for recent energy innovations. The network map in Figure 4 as a whole reflects a complex network of interrelated themes around energy transition and financial innovation, showing that the field is highly interdisciplinary, involving environmental science, technology, economics, and policy studies.

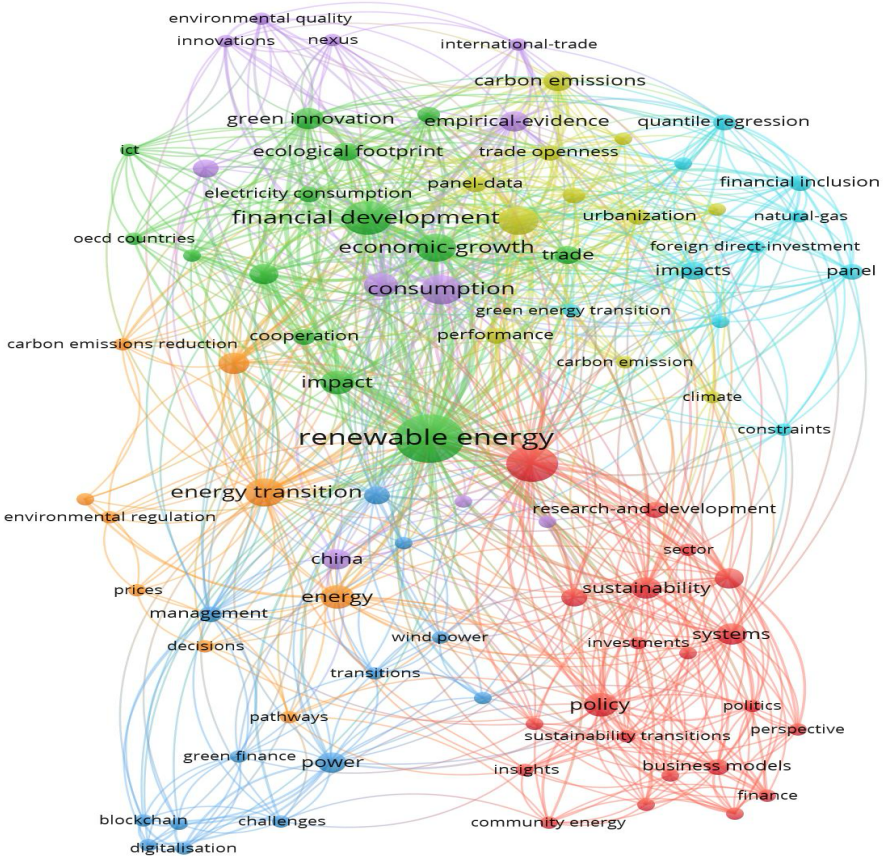

Figure 5. Bibliographic map based on the bibliometric data of the 385 publications containing the keywords "energy transition" and "financial innovation" retrieved from the WoS database
Sources: developed by the author based on VOSViewer v.1.6.15 software.

The clusters indicate that discussions in the literature cover a broad range of topics, from the technological innovations needed to support the energy transition to the economic and policy frameworks that enable it. The terms "renewable energy" and "energy transition" are quite central in the network, suggesting that they are key nodes around which much of the discussion in the literature revolves. The terms bridging multiple clusters, such as "policy", "finance", and "sustainability", highlight the interconnectedness of these topics and suggest that a holistic approach is being taken in the literature to address the challenges of energy transition and financial innovation.

6. Conclusions. As the world is undergoing a significant renewable energy transition, ensuring energy security has become a critical concern. The traditional reliance on fossil fuels has not only led to environmental degradation and climate change but also posed risks to global energy stability. Therefore, striking a balance between economic growth and the adoption of renewable sources is imperative for long-term energy security. One of the key challenges in transitioning to renewable sources is maintaining economic growth while reducing dependence on fossil fuels.

Historically, economies have heavily relied on coal, oil, and gas due to their abundance and affordability. However, this model is no longer sustainable because we face finite resources and increasing greenhouse gas emissions. To address this challenge, governments and policymakers must prioritize investments in renewable technologies that can support economic growth while reducing carbon emissions. This requires creating favourable policies that incentivize businesses to adopt cleaner energy sources through tax breaks or subsidies.

Simultaneously, funding R&D for new technologies can accelerate the transition process. Moreover, diversifying the energy mix is crucial for enhancing energy security. Relying solely on one source of energy poses risks such as price volatility or supply disruptions. By integrating various renewable sources such as solar, wind, hydroelectricity, and geothermal power into national grids, countries can ensure a more resilient and secure energy system. Overall, the relationship between energy and financial transitions is powerful and dynamic. Historical experiences in places such as Amsterdam and New York show how shifts in energy

paradigms can drive financial innovation, which in turn enables further energy shifts. Today, as the world moves towards renewable energy, we are seeing a new wave of financial innovation, from green bonds to sustainable investment portfolios. These developments are not just reshaping the financial landscape; they are also accelerating the transition to a cleaner, more sustainable energy future. However, significant challenges remain, and overcoming them will require concerted effort from governments, businesses, and individuals alike. The bibliometric network analysis results suggest that the body of literature on "energy transition" and "financial innovation" from 2015 to 2023 is diverse, covering financial, business, economic, and methodological aspects. Our results reveal that research in this area is not only multidisciplinary but also interconnected, with financial innovation playing a central role in facilitating the transition to renewable energy in different spheres, from individual firms to global economies. Furthermore, our results suggest that there are significant discussions around the implementation of these concepts within the framework of existing financial and economic systems as well as a consensus on the importance of integrating environmental considerations into economic planning and development.

In conclusion, understanding the financial implications of energy transitions is crucial for comprehending their impact on the economy. While these transitions involve significant upfront costs, they bring long-term benefits such as job creation, reduced dependence on fossil fuels, and a shift towards sustainable investments. However, it is essential to carefully manage the potential disruptions in traditional industries during this transformative process. By recognizing both the challenges and opportunities presented by energy transitions, policymakers can develop effective strategies that ensure a smooth transition towards a more sustainable future.

Conflicts of interest: The author declares no conflicts of interest.

Data availability statement: The data can be made available upon request.

Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study.

References

1. Accominotti, O., & Ugolini, S. (2020). International trade finance from the origins to the present: market structures, regulation and governance, arXiv preprint, *arXiv*, 2009.08668. [Google Scholar] [CrossRef]
2. Afshan, S., Ozturk, I., & Yaqoob, T. (2022). Facilitating renewable energy transition, ecological innovations and stringent environmental policies to improve ecological sustainability: evidence from MM-QR method. *Renewable Energy*, 196, 151–160. [Google Scholar] [CrossRef]
3. Barca, S. (2011). Energy, property, and the industrial revolution narrative. *Ecological Economics*, *70*(7), 1309–1315. [Google Scholar] [CrossRef]
4. Bhutta, U. S., Tariq, A., Farrukh, M., Raza, A., & Iqbal, M. K. (2022). Green bonds for sustainable development: Review of literature on development and impact of green bonds. *Technological Forecasting and Social Change*, 175, 121378. [Google Scholar] [CrossRef]
5. Bogdanov, D., Ram, M., Aghahosseini, A., Gulagi, A., Oyewo, A. S., Child, M., & Breyer, C. (2021). Low-cost renewable electricity as the key driver of the global energy transition towards sustainability. *Energy*, 227, 120467. [Google Scholar] [CrossRef]
6. Cantarero, M. M. V. (2020). Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries. *Energy Research & Social Science*, 70, 101716. [Google Scholar] [CrossRef]
7. Cassis, Y. (2010). *Capitals of capital: the rise and fall of international financial centres 1780-2009*. Cambridge: Cambridge University Press. [Link]
8. Cortellini, G., & Panetta, I. C. (2021). Green bond: A systematic literature review for future research agendas. *Journal of Risk and Financial Management*, *14*(12), 589. [Google Scholar] [CrossRef]
9. Croutzet, A., & Dabbous, A. (2021). Do FinTech trigger renewable energy use? Evidence from OECD countries. *Renewable Energy*, 179, 1608–1617. [Google Scholar] [CrossRef]
10. Du, J., Shen, Z., Song, M., & Vardanyan, M. (2023). The role of green financing in facilitating renewable energy transition in China: Perspectives from energy governance, environmental regulation, and market reforms. *Energy Economics*, 120, 106595. [Google Scholar] [CrossRef]
11. Dunz, N., Naqvi, A., & Monasterolo, I. (2021). Climate sentiments, transition risk, and financial stability in a stock-flow consistent model. *Journal of Financial Stability*, 54, 100872. [Google Scholar] [CrossRef]
12. ENFIN (2023). Energy Transitions and the Rise and Fall of Great Financial Centersıo [Link]
13. Grijalvo, M., & García-Wang, C. (2023). Sustainable business model for climate finance. Key drivers for the commercial banking sector. *Journal of Business Research*, 155, 113446. [Google Scholar] [CrossRef]
14. Hailiang, Z., Iqbal, W., Yin Chau, K., Raza Shah, S. A., Ahmad, W., & Hua, H. (2023). Green finance, renewable energy investment, and environmental protection: empirical evidence from BRICS countries. *Economic research*, 36(2), 2125032. [Google scholar] [CrossRef]

15. Hassan, Q., Viktor, P., Al-Musawi, T. J., Ali, B. M., Algburi, S., Alzoubi, H. M., & Jaszczur, M. (2024). The renewable energy role in the global energy Transformations. *Renewable Energy Focus*, 48, 100545. [Google Scholar] [CrossRef]
16. Hezam, I. M., Mishra, A. R., Rani, P., Cavallaro, F., Saha, A., Ali, J., Strielkowski, W., & Štreimikienė, D. (2022). A hybrid intuitionistic fuzzy-MEREC-RS-DNMA method for assessing the alternative fuel vehicles with sustainability perspectives. *Sustainability*, *14*(9), 5463. [Google Scholar] [CrossRef]
17. Hoicka, C. E., Lowitzsch, J., Brisbois, M. C., Kumar, A., & Camargo, L. R. (2021). Implementing a just renewable energy transition: Policy advice for transposing the new European rules for renewable energy communities. *Energy Policy*, 156, 112435. [Google Scholar] [CrossRef]
18. IRENA (2020). Energy Transformation Can Create More than 40 m Jobs in Renewable Energy. [Link]
19. JI, M., & Zhang, X. (2023). Assessing the impacts and mechanisms of green bond financing on the enhancement of green management and technological innovation in environmental conservation enterprises. *Journal of the Knowledge Economy*, 31, 10032–10044. [Google Scholar] [CrossRef]
20. Jiang, Z., Lyu, P., Ye, L., & Wenqian Zhou, Y. (2020). Green innovation transformation, economic sustainability and energy consumption during China's new normal stage. *Journal of Cleaner Production*, 273, 123044. [Google Scholar] [CrossRef]
21. Kalair, A., Abas, N., Saleem, M. S., Kalair, A. R., & Khan, N. (2021). Role of energy storage systems in energy transition from fossil fuels to renewables. *Energy Storage*, *3*(1), e135. [Google Scholar] [CrossRef]
22. Kennedy, C. A. (2023). Biophysical economic interpretation of the Great Depression: A critical period of an energy transition. *Journal of Industrial Ecology*, *27*(4), 1197–1211. [Google Scholar] [CrossRef]
23. Kuzmin, E., Vlasov, M., Strielkowski, W., Faminskaya, M., & Kharchenko, K. (2023). Human capital in the sustainable economic development of the energy sector, arXiv preprint, *arXiv*, 2312.06450. [Google Scholar] [CrossRef]
24. Le Billon, P., & Kristoffersen, B. (2020). Just cuts for fossil fuels? Supply-side carbon constraints and energy transition. *Environment and Planning A: Economy and Space*, *52*(6), 1072–1092. [Google Scholar] [CrossRef]
25. Li, M., Hamawandy, N. M., Wahid, F., Rjoub, H., & Bao, Z. (2021). Renewable energy resources investment and green finance: Evidence from China. *Resources Policy*, 74, 102402. [Google Scholar] [CrossRef]
26. Liu, H., Yao, P., Latif, S., Aslam, S., & Iqbal, N. (2022). Impact of Green financing, FinTech, and financial inclusion on energy efficiency. *Environmental Science and Pollution Research*, 29, 18955–18966. [Google Scholar] [CrossRef]
27. Luderer, G., Madeddu, S., Merfort, L., Ueckerdt, F., Pehl, M., Pietzcker, R., & Kriegler, E. (2022). Impact of declining renewable energy costs on electrification in low-emission scenarios. *Nature Energy*, *7*(1), 32–42. [Google Scholar] [CrossRef]
28. Miller, M. B. (2012). *Europe and the maritime world: A twentieth-century history*. Cambridge: Cambridge University Press. [Link]
29. Moe, E. (2010). Energy, industry and politics: Energy, vested interests, and long-term economic growth and development. *Energy*, *35*(4), 1730–1740. [Google Scholar] [CrossRef]
30. Muratori, M., Alexander, M., Arent, D., Bazilian, M., Cazzola, P., Dede, E. M., & Ward, J. (2021). The rise of electric vehicles—2020 status and future expectations. *Progress in Energy*, *3*(2), 022002. [Google Scholar] [CrossRef]
31. Ng, A. W., Nathwani, J., Fu, J., & Zhou, H. (2021). Green financing for global energy sustainability: prospecting transformational adaptation beyond Industry 4.0. *Sustainability: Science, Practice and Policy*, *17*(1), 377–390. [Google Scholar] [CrossRef]
32. Onifade, S. T., & Alola, A. A. (2022). Energy transition and environmental quality prospects in leading emerging economies: the role of environmental-related technological innovation. *Sustainable Development*, *30*(6), 1766–1778. [Google Scholar] [CrossRef]
33. Osman, A. I., Chen, L., Yang, M., Msigwa, G., Farghali, M., Fawzy, S., & Yap, P. S. (2023). Cost, environmental impact, and resilience of renewable energy under a changing climate: a review. *Environmental Chemistry Letters*, *21*(2), 741–764. [Google Scholar] [CrossRef]
34. Ostergaard, P. A., Duic, N., Noorollahi, Y., Mikulcic, H., & Kalogirou, S. (2020). Sustainable development using renewable energy technology. *Renewable Energy*, 146, 2430–2437. [Google Scholar] [CrossRef]
35. Polzin, F., & Sanders, M. (2020). How to finance the transition to low-carbon energy in Europe? *Energy Policy*, 147, 111863. [Google Scholar] [CrossRef]
36. Qadir, S. A., Al-Motairi, H., Tahir, F., & Al-Fagih, L. (2021). Incentives and strategies for financing the renewable energy transition: A review. *Energy Reports*, 7, 3590–3606. [Google Scholar] [CrossRef]
37. Rzayeva, U., Guliyeva, A., & Jafarova, N. (2021). Analysis of some indicators by means of fuzzy logic on the example of Azerbaijani energy enterprises. *E3S Web of Conferences*, 250, 02001. [Google Scholar] [CrossRef]
38. Saadaoui, H., & Chtourou, N. (2023). Do institutional quality, financial development, and economic growth improve renewable energy transition? Some Evidence from Tunisia. *Journal of the Knowledge Economy*, *14*(3), 2927–2958. [Google Scholar] [CrossRef]

39. Sadiq, M., Amayri, M. A., Paramaiah, C., Mai, N. H., Ngo, T. Q., & Phan, T. T. H. (2022). How green finance and financial development promote green economic growth: deployment of clean energy sources in South Asia. *Environmental Science and Pollution Research*, *29*(43), 65521–65534. [Google Scholar] [CrossRef]
40. Sciarelli, M., Cosimato, S., Landi, G., & Iandolo, F. (2021). Socially responsible investment strategies for the transition towards sustainable development: The importance of integrating and communicating ESG. *The TQM Journal*, *33*(7), 39-56. [Google Scholar] [CrossRef]
41. Seibert, M. K., & Rees, W. E. (2021). Through the eye of a needle: an eco-heterodox perspective on the renewable energy transition. *Energies*, *14*(15), 4508. [Google Scholar] [CrossRef]
42. Semieniuk, G., Campiglio, E., Mercure, J. F., Volz, U., & Edwards, N. R. (2021). Low-carbon transition risks for finance. *Wiley Interdisciplinary Reviews: Climate Change*, *12*(1), e678. [Google Scholar] [CrossRef]
43. Sinha, A., Ghosh, V., Hussain, N., Nguyen, D. K., & Das, N. (2023). Green financing of renewable energy generation: Capturing the role of exogenous moderation for ensuring sustainable development. *Energy Economics*, 126, 107021. [Google Scholar] [CrossRef]
44. Strielkowski, W. (2019). *Social Impacts of Smart Grids: The Future of Smart Grids and Energy Market Design*. Elsevier: London. [Google Scholar]
45. Strielkowski, W. (2021). Energy research and social sciences: thinking outside the box. *E3S Web of Conferences*, 250, 07001. [Google Scholar] [CrossRef]
46. Strielkowski, W. (2024). Energy Transitions and Financial Transformation: A Case of Energy and Financial Development in Late 18th-Early 19th Century Britain. *Preprints*, 2024021180. [Google Scholar] [CrossRef]
47. Strielkowski, W., Civín, L., Tarkhanova, E., Tvaronavičienė, M., & Petrenko, Y. (2021). Renewable energy in the sustainable development of electrical power sector: A review. *Energies*, *14*(24), 8240. [Google Scholar] [CrossRef]
48. Strielkowski, W., Samoilikova, A., Smutka, L., Civín, L., & Lieonov, S. (2022). Dominant trends in intersectoral research on funding innovation in business companies: A bibliometric analysis approach. *Journal of Innovation & Knowledge*, *7*(4), 100271. [Google Scholar] [CrossRef]
49. Sunio, V., Mendejar, J., & Nery, J. R. (2021). Does the greening of banks impact the logics of sustainable financing? The case of bank lending to merchant renewable energy projects in the Philippines. *Global Transitions*, 3, 109–118. [Google Scholar] [CrossRef]
50. Taghizadeh-Hesary, F., & Yoshino, N. (2020). Sustainable solutions for green financing and investment in renewable energy projects. *Energies*, *13*(4), 788. [Google Scholar] [CrossRef]
51. Tan, K. M., Babu, T. S., Ramachandaramurthy, V. K., Kasinathan, P., Solanki, S. G., & Raveendran, S. K. (2021). Empowering smart grid: A comprehensive review of energy storage technology and application with renewable energy integration. *Journal of Energy Storage*, 39, 102591. [Google Scholar] [CrossRef]
52. Taylor, J. (2021). Inside and outside the London Stock Exchange: stockbrokers and speculation in late Victorian Britain. *Enterprise & Society*, *22*(3), 842–877. [Google Scholar] [CrossRef]
53. Udeagha, M. C., & Ngepah, N. (2023). The drivers of environmental sustainability in BRICS economies: do green finance and fintech matter? *World Development Sustainability*, 3, 100096. [Google Scholar] [CrossRef]
54. Usman, M., & Hammar, N. (2021). Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries. *Environmental Science and Pollution Research*, *28*(12), 15519–15536. [Google Scholar] [CrossRef]
55. Vakulchuk, R., Overland, I., & Suryadi, B. (2023). ASEAN's energy transition: How to attract more investment in renewable energy. Energy, Ecology and Environment, *8*(1), 1–16. [Google Scholar] [CrossRef]
56. Verde, S. F., & Borghesi, S. (2022). The International Dimension of the EU Emissions Trading System: Bringing the Pieces Together. Environmental and Resource Economics, *83*(1), 23–46. [Google Scholar] [CrossRef]
57. Wang, S., Sun, L., & Iqbal, S. (2022). Green financing role on renewable energy dependence and energy transition in E7 economies. *Renewable Energy*, 200, 1561–1572. [Google Scholar] [CrossRef]
58. Zeraibi, A., Jahanger, A., Adebayo, T. S., Ramzan, M., & Yu, Y. (2023). Greenfield investments, economic complexity, and financial inclusion-environmental quality nexus in BRICS Countries: Does renewable energy transition matter? *Gondwana Research*, 117, 139–154. [Google Scholar] [CrossRef]

Інновації в енергетиці як потужний каталізатор фінансових перетворень

Вадим Стрієлковські, Університет Каліфорнії, Берклі, США; Чеський університет природничих наук, Прага, Чеська Республіка.

Традиційно прийнято вважати, що фінансові інновації відіграють визначальну роль у процесах енергетичних переходів, сприяючи зміні від використання традиційних викопних видів палива до інтеграції відновлюваних джерел енергії. Однак, детальний аналіз взаємозв'язку між цими процесами виявляє існування взаємної динаміки, де інновації в сфері енергетики можуть істотно стимулювати фінансові трансформації. Перехід до відновлюваних джерел енергії, зокрема, потребує значних фінансових інвестицій, що стимулює розвиток нових фінансових інструментів, таких як зелені облігації та інноваційні моделі фінансування, спрямовані на підтримку сектора відновлюваної енергії. Взаємозалежність між енергетичними переходами та фінансовими інноваціями

демонструє здатність фінансових установ адаптуватися до змінних потреб ініціатив сталого розвитку. Поширення зелених енергетичних рішень спонукає фінансовий сектор до розроблення інноваційних стратегій для забезпечення цих переходів. Свідченням зростаючого академічного інтересу до дослідження цих симбіотичних відносин є збільшення кількості публікацій, проіндексованих у базі даних Web of Science, від 10 у 2015 році до 113 у 2023 році, що вказує на стрімкий розвиток досліджень з цієї проблематики. Ця стаття надає комплексний бібліометричний аналіз існуючої наукової літератури з питань взаємозв'язку між енергетичним переходом і фінансовими інноваціями. З використанням мережевого аналізу та програмного забезпечення VOSviewer автором виявлено ключові тенденції та закономірності у міждисциплінарних дослідженнях. Результати дослідження свідчать про те, що енергетичні переходи не лише отримують вигоду від фінансових інновацій, але й виступають значущими каталізаторами змін у фінансовому секторі, що підтверджується різноманітними сучасними та історичними прикладами. Вказаний взаємний вплив акцентує критичну важливість прогресу в сфері енергетики для розвитку фінансових практик та інструментарію. Дослідження, представлене в даній статті, значною мірою сприяє глибшому розумінню взаємопосилення енергетичних переходів і фінансових інновацій, що має істотні наслідки для політичних діячів, інвесторів та науковців, зосереджених на підтримці стійкості енергетичних екосистем та фінансового ринку.

Ключові слова: енергетичні інновації; сталий розвиток; відновлювальна енергія; зелене фінансування; фінансові інновації.