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Review Article

Mapping the research landscape of energy market and renewable energy: A bibliometric analysis

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Abstract. This bibliometric analysis examines the research landscape of "Renewable Energy" and "Energy Markets" from 2000 to 2023, with a specific focus on emerging trends during 2023 to 2024. The novelty of this study lies in its integration of bibliometric tools to analyse keywords, global contributions, thematic evolution, and future research directions. Using data extracted from Scopus and Web of Science (WoS), the study employs advanced bibliometric techniques, including keyword and term co-occurrence mapping through VosViewer. The findings reveal significant growth in research output in recent years, with 29 percent of Scopus and 44 percent of Web of Science publications produced during 2023 to 2024. China and the United States lead global contributions, while Malaysia and India exhibit rapid growth, each contributing more than 70 percent of their research in this period. Keyword analysis shows blockchain technologies, microgrids, and peer-to-peer energy trading as dominant themes, reflecting the rise of decentralised and digital energy systems. Thematic clusters underscore the convergence of technological innovation, policy frameworks, economic modelling, and regional strategies. Co-authorship networks reveal active collaboration across Asia-Pacific and European countries. Journal articles are the primary output type, with early-access publications highlighting the urgency of disseminating new findings. This study provides a comprehensive and up-to-date overview of the evolving discourse in renewable energy and energy markets. It offers actionable insights for researchers and policymakers while identifying underexplored areas that merit further investigation. The results support interdisciplinary approaches to addressing global energy challenges and advancing sustainable energy transitions.

Keywords: Bibliometric, Energy Market, Future Trend, Renewable Energy, Trading market

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1. Introduction

The demand for electricity has been growing exponentially, driven by rapid technological advances and the increasing global population. In today's modern technological era, nearly every aspect of human life (Javaid *et al.*, 2021). This including industry, communication, transportation, and daily activities that relies on a stable and sufficient supply of electricity (Kabeyi and Olanrewaju, 2022; Jasiūnas *et al.*, 2021). Simultaneously, the rapid growth of the world's population has expanded the need for energy infrastructure to meet this ever-growing demand (Kober *et al.*, 2020; Maksimtsev et al, 2022; Mohamad *et al.*, 2023). According to Liu *et al.* (2022), this phenomenon poses a significant challenge to ensuring adequate energy supply without compromising environmental sustainability.

Fossil fuels have long been the backbone of global energy needs for decades (Jacobs, 2021; Overland *et al.*, 2022). However, the detrimental environmental impacts of fossil fuel consumption, particularly greenhouse gas emissions that contribute to global warming (Jeffry *et al.*, 2021; Chen *et al.*, 2023), have heightened global awareness of the need to transition to more sustainable energy sources (Kabeyi and Olanrewaju, 2022). Study by Martín-Ortega *et al.* (2024), mentioned that under the Paris Agreement, countries all over the world should reducing the production of greenhouse gas. According to Loucks (2021) and Siegel (2021), global warming not only exacerbates climate change on a large scale but also threatens the stability of ecosystems, economies, and human security.

In response to these challenges, renewable energy sources such as solar, wind, hydro, and biomass have become a focal point in the global energy market (Rahman *et al.*, 2022; Hassan *et al.*, 2024a). According to Zheng and Ge (2022), dependence on these resources is steadily increasing as they provide clean, sustainable alternatives capable of significantly reducing carbon emissions. The renewable energy market is now recognised as a highly valuable sector, not only for its economic potential but also for its crucial role in advancing global sustainability agendas (Ram *et al.*, 2022; Hassan *et al.*, 2024a). Investments in renewable energy technologies are on the rise (Khan *et al.*, 2021), reflecting a growing understanding that this transition is not merely desirable but essential for long-term economic, social, and environmental benefits (Bogdanov *et al.*, 2021).

Moreover, initiatives such as international climate agreements and government policies promoting the adoption of renewable energy are accelerating this transition (Aleluia *et al.*, 2022; Falcone, 2023). Many nations are now striving to achieve carbon neutrality by the mid-century, with the shift to renewable energy seen as a cornerstone of this goal (Hassan *et al.*, 2024a;

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Dsilva *et al.*, 2024). For instance, according to Hassan et al (2024b) and Kiasari *et al.* (2024), the implementation of smart grid systems, advancements in energy storage technologies, and tax incentives for green energy investors are among the strategic measures being adopted to ensure a sustainable energy transformation (Qadir *et al.*, 2021). However, this transition is not without its challenges. According to Osman *et al.* (2023), the issues such as the high costs of developing renewable energy infrastructure, the reliance of some sources like solar and wind on weather conditions, and unequal access to these technologies in developing countries demand careful consideration (Ang *et al.*, 2022; Falcone, 2023). Enhanced international cooperation, technology transfer, and incentives for developing nations are essential to ensure this transformation is inclusive and effective (Pandey *et al.*, 2022).

There are a lot of past studies conducted related to renewable energy. The novelty of this paper lies on future trends of the topic using the resent years. The specific objectives explored in this study are:

i. Analyse the future trend renewable energy and market energy using data from Web of Science and Scopus from year 2000 to 2023.
ii. Evaluate the global contributions to renewable energy and market energy, focusing on leading nations between 2022–2023.
iii. Analyse the surge in emerging research trends in renewable energy and energy markets (2023–2024).
iv. Identify the ten highly cited publications on renewable energy and market energy.
v. Explore the VosViewer mapping the interconnected keywords and terms in a renewable energy and market energy research.

This bibliometric analysis uniquely integrates keyword co-occurrence mapping with advanced bibliometric techniques to explore both historical and emerging research trends specifically within the intersection of "Energy Market" and "Renewable Energy" from 2000 to 2023, with particular emphasis on the recent surge in publications during 2023–2024. Unlike previous bibliometric studies, this research explicitly focuses on identifying cutting-edge research themes such as blockchain technologies, microgrids, and peer-to-peer energy trading, providing fresh insights into the evolving landscape of renewable energy markets. Furthermore, this paper uniquely evaluates global contributions at the country level, spotlighting not only traditional leaders such as China and the United States but also rapidly emerging contributors like Malaysia and India, thus enriching the understanding of geographical shifts and policy-driven research trends.

2. Literature review

The field of renewable energy research has seen significant growth and diversification over the past few decades, as evidenced by various bibliometric analyses that provide insights into trends, challenges, and emerging areas of focus. This literature review synthesizes findings from recent studies, highlighting focussing area and contributions from the keyword renewable energy in bibliometrics studies. Mentel *et al.* (2023) underscore the critical role of innovation across technology, business processes, and policy frameworks in driving the transition to renewable energy. Highlighting that the energy sector contributes 75% of global greenhouse gas emissions, their study emphasises the urgency of adopting innovative solutions to mitigate climate change. Similarly, Khalili and Breyer (2022) explore renewable energy systems, offering a historical perspective that traces this research focus back to 1975. Together, these studies underline the importance of comprehensive system transitions and technological advancements in achieving sustainable energy goals.

Zhang *et al.* (2022) expand this discussion by examining the integration of artificial intelligence (AI) into renewable energy systems. Their bibliometric analysis reveals how AI optimises energy production and grid management, offering a promising pathway for enhancing system efficiency. Complementing this technological perspective, Azevedo *et al.* (2019) analyse the complexities of renewable energy supply chains, emphasising logistics and distribution as critical factors for large-scale implementation. Hasan *et al.* (2023) contribute to this discourse by mapping the landscape of biodiesel and renewable energy studies, emphasising the role of biofuels in addressing environmental concerns. Collectively, these studies provide a multifaceted view of the technological advancements necessary for effective renewable energy adoption.

Jabeen *et al.* (2020) focus on the sustainability of renewable energy sources, including biofuels, solar, and wind energy, highlighting developed countries' trends in replacing fossil fuels. This complements the findings of Elie *et al.* (2021), who address the financial mechanisms underpinning renewable energy transitions. Elie *et al.* stress the importance of adequate funding, which aligns with Kristia and Rabbi (2023) exploration of the intersection between renewable energy and the circular economy. Their study identifies regulatory and financial constraints as key barriers to integrating renewable technologies within a circular economy framework.

These perspectives are further enriched by Nunes *et al.* (2023), who classify public policies supporting renewable energy into distributive, redistributive, and regulatory types. Their findings highlight Germany's leadership in policy development, reflecting the broader global shift towards renewable energy as a cornerstone of sustainable development. Similarly, Marco-Lajara *et al.* (2023) connect renewable energy research to Sustainable Development Goals (SDGs), noting the growth in academic contributions since 2015. There also a similar study that explore green policy in themes related to efficient energy use and greenhouse gas emissions, which providing insights into the evolution of research in this area and the implications for policy-making (Ziabina and Pimonenko, 2020). Qin *et al.* (2022) on the other hand, investigated the determinants of green energy adoption through a bibliometric lens. Their analysis reveals critical factors influencing the uptake of green technologies, providing insights that can inform policy and strategic planning in renewable energy sectors.

In the context of renewable energy between regional analyses reveal distinct patterns and challenges, Kut and Pietrucha-Urbanik (2023) examines renewable energy research in two European countries, identifying critical gaps in energy storage and smart grid technologies. Similarly, Zwane *et al.* (2022) focus on solar energy forecasting in Africa, emphasising the need for targeted research to address regional challenges. Moreover, a study by Afrane et al (2022), analyse the bibliometrics of renewable energy in Africa within year 1991 until 2021 using the WOS database. These studies contrast with Yang (2024), who investigates renewable energy investments in Belt and Road Initiative countries, underscoring their strategic importance for sustainable development.

Hu *et al.* (2022) explore ocean renewable energy, identifying hotspots and emerging trends in marine energy research. Meanwhile, Sotnyk (2023) examines household energy efficiency alongside renewable energy, providing insights into collaborative networks and research evolution. Together, these studies highlight the dynamic and diversified nature of renewable energy research. Sector-specific analyses also contribute valuable insights as a study by Ogarek *et al.* (2023)

Table 1
ScientoPy pre-processing

Result stage	ScientoPy Pre-Processing Output	Amount	(%)
Initial Results	Total papers from Raw data (Scopus and WoS)	307	-
	Omitted papers by document type (Automatic type-filter publication)	22	7.2
	Total papers after omitted papers removed (Total publications after selection)	285	-
	Publications in WoS	69	24.2
	Publications in Scopus	216	75.8
Duplicate Removal	Duplicated publications in both databases	55	19.3
	Duplicated publications from WoS	0	0
	Duplicated publications from Scopus	55	25.5
	Total papers after removing duplicates	230	-
Final Results	Final selected paper from WoS	69	30
	Final selected paper from Scopus	161	70

focus on hydrogen as a renewable energy carrier, identifying research gaps in hybrid configurations of distributed energy systems, particularly in under-researched regions like South America and Africa. Hassan and Awad (2023) add a practical dimension by analysing hybrid renewable energy-driven desalination technologies, illustrating renewable energy's potential in addressing water scarcity.

Sarkodie and Owusu (2023) explore the water-energy-food nexus, emphasising integrated approaches to resource management. This complements the work of Annibaldi *et al.* (2020), who review renewable energy policies, noting both positive and critical aspects influencing technology adoption. Córdova and Rojas-Ortega (2023) quantify institutional and national contributions to renewable energy research, identifying leading contributors and collaboration patterns. This aligns with Lillo *et al.* (2023), who stress the need for interfirm cooperation to accelerate technological advancements. The also bibliometric study related to the quality management within industry 4.0 (Kwilinski, 2024)

The Study by Sharma and Sengar (2021), analyse the bibliometric of the evolution and future trajectories of renewable energy research from 2000–2023 using Scopus database. The study targeted various publications specifically mentioning "renewable energy" and "renewable energies" in their titles, examining publication trends, research areas, geographic origins, institutional affiliations, funding patterns, journal contributions and citation impacts. The study of renewable energy in bibliometric also been done by Hou and Wang (2021), evolutionary tracks of studies in the field of energy, environment, and climate change from 1990 to 2019 using WoS database. There are a lot of studies conducted a bibliometric focusing on renewable energy. However, this paper fil the gap by conducting a comprehensive bibliometric analysis of renewable energy in context of market energy from year 2000 until 2023 using the Scopus and WoS databases.

3. Methodology

This bibliometric analysis examines the research landscape of renewable energy and energy markets from 2000 to 2023, with a specific focus on identifying emerging trends during 2023–2024. A systematic bibliometric approach was employed to ensure the rigor and reproducibility of the findings, encompassing data collection, pre-processing, cleaning, analysis, and visualization (Khan *et al.*, 2022; Mohamad *et al.*, 2024b). The data collection process utilized two prominent academic databases which are Scopus and Web of Science (WoS). These platforms were selected for their extensive coverage of peer-reviewed literature and robust metadata, making them ideal for bibliometric analysis.

The search queries were meticulously designed to capture relevant publications. For Scopus, the query included terms such as "energy market*," "energy trading*," "renewable energy," and "green energy," with the publication years restricted to 2000–2024. Similarly, the WoS query targeted publications with titles containing "energy market*" and "renewable energy" within the same timeframe. The Scopus research string: TITLE ("energy market*" OR "Energy trading*" AND "renewable energy" OR "green energy") AND PUBYEAR > 1999 AND PUBYEAR < 2025. The search retrieved a total of 307 records, comprising 69 papers from WoS (24.2%) and 216 papers from Scopus (75.8%). After excluding non-relevant papers such as editorials and letters (7.2% of the initial dataset), 285 papers were deemed suitable for further analysis.

The ScientoPy pre-processing stage in Table 1 was critical to refine the dataset and ensure its quality. Initially, duplicates between Scopus and WoS datasets were identified and removed. A total of 55 duplicate papers (19.3% of the dataset) were found, and all were removed from Scopus, while none were removed from WoS. Of these duplicates, 35 were retained for further evaluation due to variations in their citation counts. Following this step, the dataset was reduced to 230 unique papers, with 69 papers from WoS (30.0%) and 161 papers from Scopus (70.0%). Additionally, the dataset's document types were analyzed: WoS contributed 54 articles (23.5%), 2 reviews (0.9%), and 13 proceedings papers (5.7%), while Scopus provided 86 articles (37.4%) and 10 reviews (4.3%).

The cleaning phase further refined the dataset to maintain consistency and accuracy. This involved standardizing author names, keywords, and publication details across the datasets (Mohamad *et al.*, 2024a). Any records missing critical bibliographic details or metadata were excluded. This process ensured the dataset's suitability for bibliometric analysis and eliminated any inconsistencies that could compromise the reliability of the results. By integrating systematic data collection, pre-processing, cleaning, and advanced analysis, this study provides a robust framework for exploring the intersection of renewable energy and energy markets. The incorporation of pre-processed data ensures the accuracy and reliability of the findings, offering valuable insights into past and emerging trends in the field.

The analysis workflow was structured to provide a detailed understanding of the research landscape. Descriptive analyses revealed trends in publication outputs, prolific authors, and influential journals. Network analyses identified collaboration dynamics and thematic clusters within the field, while emerging trends for 2023–2024 were identified using advanced bibliometric methods. The combination of these analyses provided a holistic view of the research landscape. Visualization was a key component of the study, facilitating the interpretation of complex relationships within the dataset. Network maps, bar charts, and trend graphs were generated using VosViewer,

ScientoPy and Excel. These visualizations presented the findings in an accessible and interpretable format, enabling a clear understanding of the dynamics of renewable energy and energy markets

4. Results and Discussion

4.1 Pattern of the Web of Science and Scopus in renewable energy

The global transition toward renewable energy has spurred significant academic interest, particularly in exploring the intricate relationship between energy markets and sustainable energy sources. This study analyses recent trends in scholarly publications on "energy market*" and "renewable energy" across Scopus and Web of Science (WoS) databases, focusing on the total volume of publications and the share of recent contributions from 2023 to 2024. By comparing the 2 databases in Figure 1, the Scopus has a notably higher total number of publications on energy markets and renewable energy compared to WoS.

While the absolute number of documents in Scopus is higher, the proportion of recent publications (2023–2024) stands at 29%. This indicates a steady but less pronounced focus on emerging research trends in Scopus relative to WoS. In contrast, WoS exhibits a smaller total volume of publications but a significantly higher share of recent contributions, with 44% of documents published between 2023 and 2024. This pattern suggests that WoS has been particularly adept at capturing the surge of cutting-edge research in the past two years, reflecting its emphasis on indexing high-impact and contemporary studies. The differences in publication patterns between Scopus and WoS highlight the evolving nature of academic discourse in energy markets and renewable energy. The substantial increase in recent publications, particularly in WoS, is indicative of the growing urgency to address global energy challenges such as decarbonization, energy security, and market restructuring.

The Figure 2, line chart illustrates the temporal trends in research publications on "renewable energy" and "energy market*" indexed in Scopus and Web of Science (WoS) from 2001 to 2024. During the initial years (2001–2010), both Scopus and WoS show limited research output in this field. This period corresponds to the nascent stage of renewable energy research, with fewer publications likely reflecting the relatively low global emphasis on renewable energy and energy market integration. Scopus exhibits a gradual increase in research activity, reflecting its broader coverage across disciplines. In contrast, WoS records sporadic publications, indicative of its focus on high-impact, targeted studies during this early phase. The

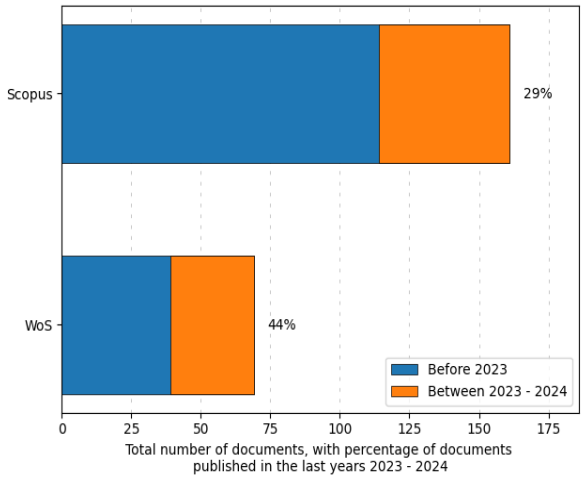

Fig 1. Comparison of Scopus and Web of Science Databases

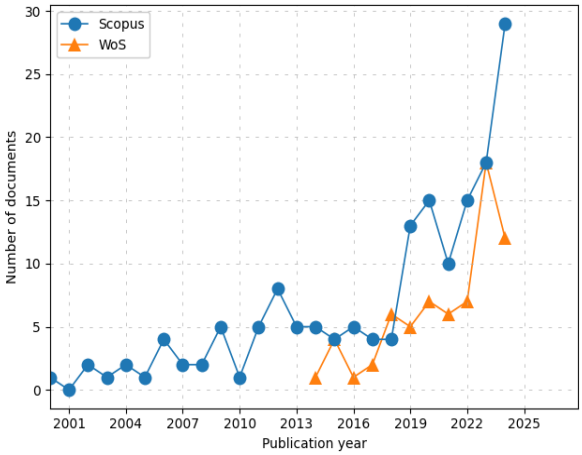

Fig 2. Trends in Research on Energy Markets and Renewable Energy in Scopus and Web of Science Databases

publication trends begin to diverge significantly after 2010. Scopus shows a steady rise in the number of publications, reflecting the global surge in renewable energy research fueled by technological advancements and policy commitments like the Paris Agreement in 2015.

From 2019 onwards, both Scopus and WoS show a sharp increase in publication volume, marking a period of intensified research activity. Scopus leads with a dramatic rise, peaking in 2024. This growth underscores its comprehensive indexing strategy, capturing a wide array of studies across diverse subfields. WoS also exhibits a noticeable surge, although its publication volume is comparatively lower. This indicates a focus on emerging, high-priority topics within the field, reflecting its emphasis on impactful and cutting-edge research. The most significant spike in Scopus occurs between 2023 and 2024, likely driven by global efforts to meet renewable energy targets and transition to sustainable energy systems. WoS follows a similar pattern, albeit at a more moderate scale, underscoring its targeted approach. Therefore, there are dramatic rises in publications for both databases during the last five years signals a growing urgency in addressing global energy challenges.

4.2 Global Trends in Renewable Energy and Energy Market Research: A Country-Level Analysis (2023–2024)

The bar chart in Figure 3 presents an insightful comparison of the total number of documents published on "energy market*" and "renewable energy" across various countries, segmented by those published before 2023 and during the period 2023–2024. The analysis provides a nuanced understanding of global research contributions, highlighting both the volume of research output and the proportion of recent publications. China leads the global research output in this domain, with a total publication volume significantly higher than other countries. Notably, 40% of these publications were released during 2023–2024, reflecting the country's strong commitment to advancing research in renewable energy and energy markets. This surge aligns with China's ambitious renewable energy targets and its leadership in renewable technology production and deployment (Zhang *et al.*, 2022; Qin *et al.*, 2022).

The United States follows as the second-largest contributor, with 24% of its publications from the recent period as similar result with Tan *et al.* (2021). While the proportion is lower

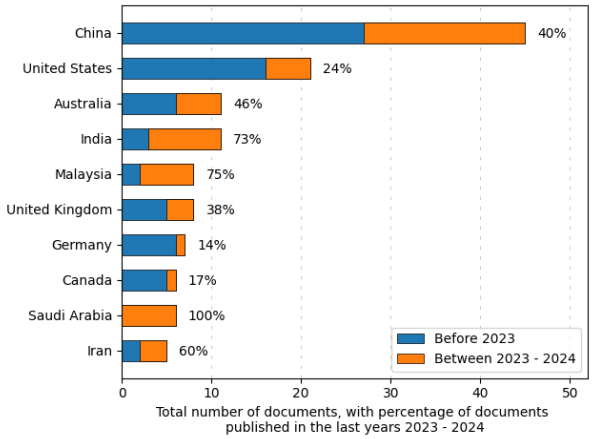

Fig 3. Global Trends in Renewable Energy and Energy Market Research

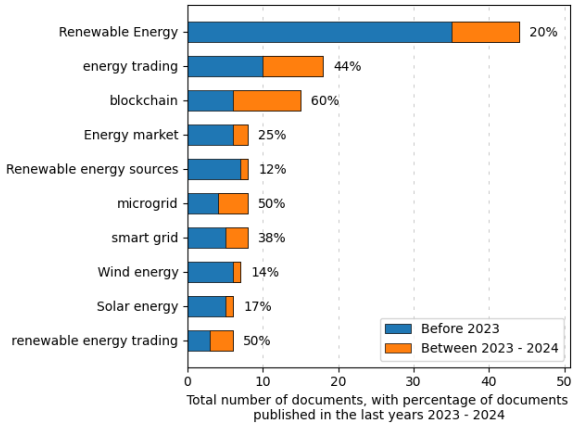

Fig 4. Keyword Analysis of Energy Markets and Renewable Energy

compared to China, the absolute number of recent publications still highlights the United States' sustained investment in cutting-edge energy research. The focus on innovative market mechanisms and renewable integration underscores the country's efforts to modernize its energy systems and address climate challenges. India and Malaysia demonstrate remarkable recent activity, with 73% and 75% of their respective publications from 2023–2024. These high proportions suggest a rapid acceleration in research output, driven by national policies aimed at renewable energy expansion and energy market reform. India's focus on large-scale solar and wind projects, combined with initiatives to create efficient energy markets, has likely fueled this growth.

Similarly, Malaysia's emphasis on transitioning to sustainable energy systems and its active participation in global climate agreements have spurred academic interest. The high percentage of recent publications highlights Malaysia's emerging role as a key player in renewable energy research within Southeast Asia (Fahim *et al.*, 2023). Australia and Iran also exhibit noteworthy trends, with 46% and 60% of their publications from the 2023–2024 period. Australia's research activity is consistent with its commitment to renewable energy leadership, particularly in solar and wind technologies. The focus on integrating these renewables into its energy markets has made Australia a prominent contributor to the global discourse. Interestingly, Saudi Arabia stands out with 100% of its publications released during 2023–2024, reflecting a newfound focus on renewable energy research. This aligns with Saudi Vision 2030, which emphasizes diversification of the economy and a transition from oil dependence. The kingdom's recent investments in solar and wind energy projects are likely driving this surge in academic output.

4.3. Emerging Research Trends in Energy Markets and Renewable Energy: A Keyword Analysis (2023–2024)

The bar chart in Figure 4 offers an insightful breakdown of the total number of documents associated with prominent keywords in the field of "energy market*" and "renewable energy." It distinguishes publications before 2023 from those during 2023–2024, highlighting the growing focus on specific areas within this rapidly evolving research domain. "Renewable Energy" emerges as the most frequently used keyword, with a total publication volume significantly surpassing other terms. However, only 20% of these publications were produced during 2023–2024, indicating that while the topic remains a cornerstone of the research field, much of the foundational work has already been established in prior years.

Keywords such as "blockchain" and "energy trading" show notable growth in recent years, with 60% and 44% of their respective publications emerging between 2023 and 2024. The strong presence of "blockchain" highlights the increasing interest in leveraging decentralized technologies for energy markets, including peer-to-peer trading, energy traceability, and improving transaction efficiency. Similarly, the emphasis on "energy trading" reflects ongoing developments in creating dynamic and efficient energy markets that accommodate the variable nature of renewable energy sources (Lorente *et al.*, 2023). The keywords "microgrid" and "renewable energy trading" exhibit an equal proportion of recent publications (50%), suggesting a surge in interest in distributed energy systems and niche market mechanisms. According to Vergados *et al.* (2016), microgrids, which enhance grid resilience and enable localized energy management, have gained attention as critical components of sustainable energy transitions. Similarly, renewable energy trading represents a specific focus on creating market structures that prioritize renewable energy transactions, emphasizing efficiency and sustainability.

The keywords "smart grid" and "energy market" also feature prominently, with 38% and 25% of their publications from 2023–2024, respectively. These topics highlight ongoing efforts to modernize energy infrastructure through advanced technologies and optimize market mechanisms for renewable energy integration. The continued interest in smart grids underscores the importance of enabling technologies like demand response, energy storage, and real-time data analytics to manage the complexities of modern energy systems (Kiasari *et al.*, 2024). Interestingly, "wind energy" and "solar energy" have relatively low proportions of recent publications (14% and 17%, respectively).

4.4 Author Contributions and Publication Trends in Renewable Energy and Energy Markets (2001–2024)

The Figure 5 visualizations provide a dual perspective on the contributions of leading authors in the field of renewable energy and energy markets. The left panel illustrates the cumulative number of documents published by key authors over time, while the right panel highlights their average annual contributions during 2023–2024 and the percentage of documents published within this period. These patterns shed light on the evolving landscape of individual scholarly contributions. In the cumulative publication chart, Wang Y. leads with the highest

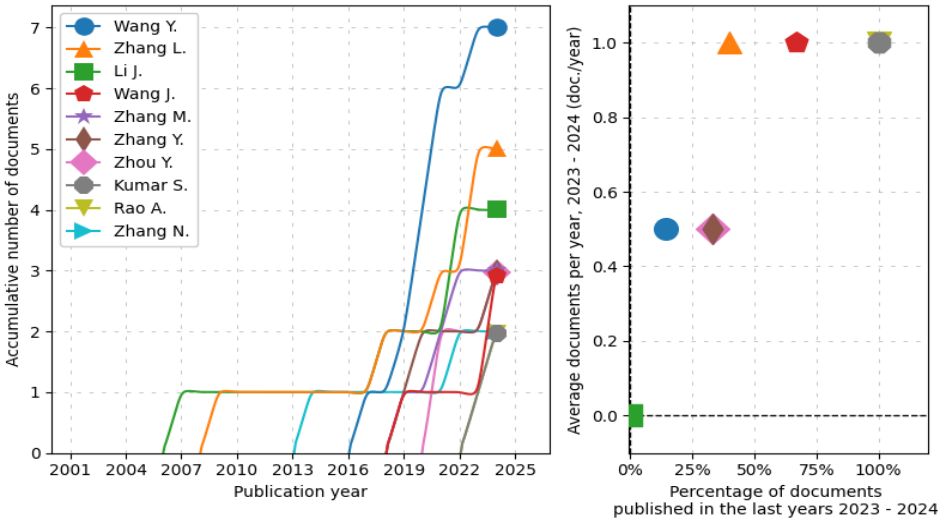

Fig 5. Author Contributions and Publication Trends

number of publications, showcasing consistent contributions from 2016 onward and a significant surge after 2020. This upward trend reflects a strong and sustained research focus, likely in response to the growing importance of renewable energy in global policy and market discussions.

Zhang L. and Zhang M. follow closely, with steep growth trajectories beginning in the early 2020s. Their publication patterns suggest an intensification of research activity during this period, possibly driven by advancements in market mechanisms and emerging technologies like blockchain and smart grids. Other authors, including Zhou Y. and Rao A., show more recent entry points into the field, with their cumulative publications accelerating sharply post-2022. This indicates that these researchers may be addressing specific, rapidly evolving topics in the domain, contributing fresh perspectives and expertise.

The right panel highlights authors' average publication rates during 2023–2024 and the share of their total contributions within this period. Zhang L. stands out with the highest average annual output and 100% of their publications over the past two years. This indicates a focused and highly active research phase, potentially targeting cutting-edge developments in renewable energy markets. Similarly, Rao A. exhibits a significant concentration of contributions in the recent period, suggesting engagement with emerging topics. On the other hand, Wang Y., despite a lower percentage of recent publications, maintains a steady average output, reflecting ongoing involvement in foundational or established areas of research.

4.5 Document Types in Renewable Energy and Energy Market Research (2023–2024)

The bar chart provides a breakdown of research output in the field of "renewable energy" and "energy market*" based on document types (in Figure 6), with a distinction between publications before 2023 and those published during 2023–2024. Journal articles form the majority of research output, with a total volume far exceeding other document types. Notably, 44% of these articles were published between 2023 and 2024, reflecting the growing interest in renewable energy and energy markets during this period. Journal articles remain the gold standard for disseminating comprehensive research findings, offering detailed analyses that contribute significantly to the theoretical and empirical foundations of the field. The high proportion of recent journal articles underscores the ongoing

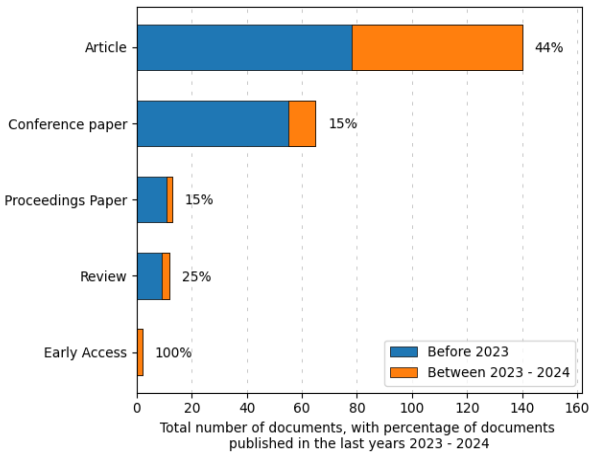

Fig 6. Document Types

innovation and advancements in renewable energy technologies, market mechanisms, and policy frameworks. It also highlights the role of peer-reviewed journals in validating and propagating cutting-edge research. Conference papers account for the second largest share of documents, with 15% of them published in the last two years.

Conferences serve as critical venues for presenting preliminary findings, discussing emerging ideas, and fostering collaboration among researchers. The relatively lower percentage of recent contributions suggests that while conferences remain important, a substantial portion of impactful research transitions to journal articles for broader dissemination.

Early-access publications represent a unique category with 100% of documents published in 2023–2024. This reflects the urgency of disseminating timely research findings in response to global energy challenges. Early-access articles enable researchers and policymakers to access new insights without delay, accelerating the adoption of innovative solutions in renewable energy and energy markets. Reviews and proceedings papers collectively make up a smaller portion of the research output, with 25% and 15% of their respective publications released recently. Review articles play a pivotal role in synthesizing existing knowledge, identifying research gaps, and setting future agendas.

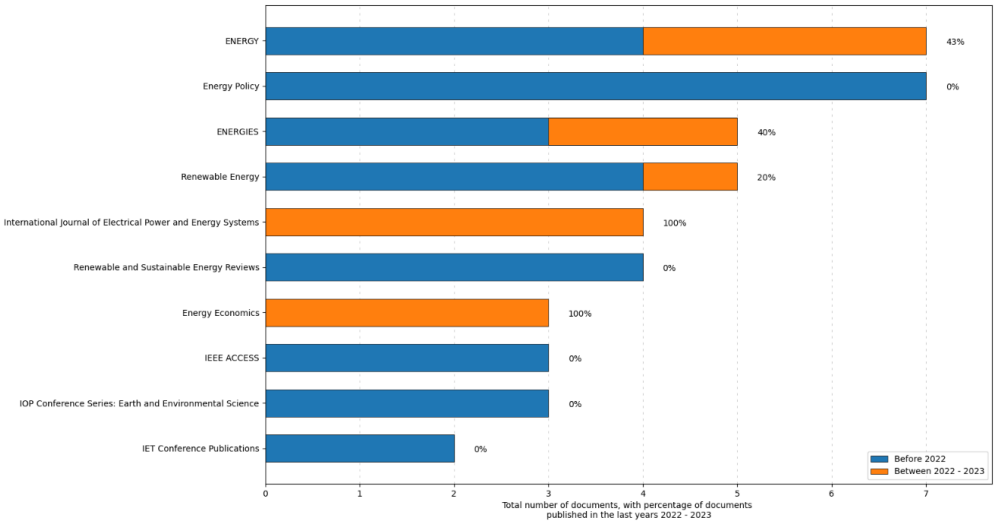

Fig 7. Journal Contributions to Renewable Energy and Energy Market Research

The recent reviews suggest an ongoing effort to consolidate findings from the rapidly growing body of literature. Proceeding papers, often derived from conference presentations, offer concise accounts of specific studies or methodologies. The relatively modest proportion of recent proceedings papers indicates a preference for transitioning key conference outputs into journal articles or reviews for wider accessibility.

4.6 Journal Contributions to Renewable Energy and Energy Market Research (2022–2023)

Figure 7 shown on the bar chart offers an overview of the journals contributing to research in the fields of "renewable energy" and "energy market*" between 2022 and 2023, highlighting the total number of documents published and the proportion of recent contributions. The journal Energy leads in terms of overall publications, with 43% of its output from 2022–2023. As one of the most prominent journals in the energy research domain, this reflects its consistent contribution to addressing broad topics, from energy policy and market dynamics to technological innovations (Qin *et al.*, 2022).

According to Kabeyi and Olanrewaju (2022), the substantial proportion of recent publications underscores its continued relevance in fostering research aligned with global energy transitions. Energy Policy follows closely with a strong publication record, though notably, all of its contributions preceded by 2022 (Khalili and Breyer, 2022). This absence of recent publications might suggest a shift in focus or decreased emphasis on this venue for studies related to renewable energy and energy markets. However, its historical influence remains significant, particularly in shaping discussions around regulatory frameworks and market-based approaches to energy management.

The journal Energies exhibits significant activity, with 40% of its publications emerging in the last two years. This balance between earlier and recent contributions highlights its role as a dynamic platform for both foundational and cutting-edge research, particularly in renewable technologies and decentralised energy systems. Renewable Energy, another prominent journal in the field, shows a smaller but still meaningful 20% of its publications coming from 2022–2023. As a journal with a specialised focus on renewable technologies, this trend reflects a stable flow of research that consolidates existing knowledge while incorporating recent advancements.

The International Journal of Electrical Power and Energy Systems and Renewable and Sustainable Energy Reviews display contrasting trends. The former has 100% of its publications from 2022–2023, indicating an intensified focus on recent developments in energy systems and their market applications. This suggests a targeted emphasis on bridging electrical power technologies with economic and policy considerations. Conversely, Renewable and Sustainable Energy Reviews has no publications within this period, despite being a highly regarded source for synthesising knowledge. Its absence of recent contributions might imply a focus on large-scale review articles rather than regular submissions.

4.7 Highly Cited Research on Renewable Energy and Energy Markets

Table 2 shows the overview of the ten most-cited publications in the fields of renewable energy and energy markets. The paper by Martinot *et al.* (2002) leads in citation count with 354 citations, highlighting its seminal influence. It provides a comprehensive review of renewable energy market evolution in developing countries. The study's emphasis on rural entrepreneurship, government interventions, and donor assistance underscores the importance of multifaceted approaches in scaling renewable energy solutions. The exploration of market-oriented strategies has set the foundation for subsequent studies, particularly in low-income contexts, where renewable energy plays a dual role in addressing energy access and sustainable development. Similarly, Wüstenhagen and Bilharz (2006) examine Germany's green energy market, identifying the critical role of feed-in laws and consistent policy support in fostering renewable energy adoption. With 319 citations, the paper's case-based insights into policy design and market-driven approaches have informed strategies in other nations aiming to replicate Germany's success.

Ferruzzi *et al.* (2016), with 128 citations, delve into the challenges of bidding strategies in day-ahead energy markets under renewable energy production uncertainty. This paper's innovative use of the Analog Ensemble (AnEn) method to estimate uncertainty showcases the intersection of computational techniques with energy market strategies. The focus on residential microgrids (MGs) highlights the decentralisation of energy systems and the role of prosumers in shaping future energy markets. Similarly, Vergados *et al.* (2016) explore clustering algorithms to optimise renewable energy trading among prosumers. The emphasis on reducing forecast

Table 2
Highly Cited Research on Renewable Energy and Energy Markets

Author's	Title	Cited	Sources Data
Martinot et al. (2002)	Renewable energy markets in developing countries	354	Scopus
Wustenhagen and Bilharz (2006)	Green energy market development in Germany: effective public policy and emerging customer demand	319	Scopus
Ferruzzi et al. (2016)	Optimal bidding in a Day-Ahead energy market for Micro Grid under uncertainty in renewable energy production	128	Web of Science
Lorente et al. (2023)	Dynamic connectedness among climate change index, green financial assets and renewable energy markets: Novel evidence from sustainable development perspective	125	Web of Science
Pereira et al. (2012)	The renewable energy market in Brazil: Current status and potential	123	Scopus
Venetsanos et al. (2002)	Renewable energy sources project appraisal under uncertainty: The case of wind energy exploitation within a changing energy market environment	117	Scopus
Nicolli and Vona (2019)	Energy market liberalization and renewable energy policies in OECD countries	94	Web of Science
Vergados et al. (2016)	Prosumer clustering into virtual microgrids for cost reduction in renewable energy trading markets	89	Scopus
Liu et al. (2021)	Peer-to-peer energy trading of net-zero energy communities with renewable energy systems integrating hydrogen vehicle storage	78	Scopus

inaccuracies and operational costs highlights the economic potential of virtual microgrids. This paper (89 citations) has practical implications for decentralised energy systems, particularly in enhancing the cost-effectiveness of renewable energy adoption.

Pereira *et al.* (2012) and Nalan *et al.* (2009) focus on renewable energy's role in sustainable development within Brazil and Turkey, respectively. Pereira *et al.* (123 citations) emphasise Brazil's strategic efforts to expand its renewable energy matrix, underpinned by policies fostering low-carbon growth. Similarly, Nalan *et al.* (78 citations) examine barriers and market conditions in Turkey, offering a critical lens into policy and knowledge gaps that hinder renewable energy adoption in emerging economies. These papers collectively underscore the necessity of robust policy frameworks and localised strategies to overcome barriers to renewable energy expansion, particularly in countries with significant untapped potential. The recent study by Lorente *et al.* (2023) (125 citations) integrates renewable energy markets with green financial assets and geopolitical risks, offering novel insights into the interconnectedness of financial and energy systems. Using Quantile Vector Autoregressive (QVAR) models, the study highlights the influence of geopolitical events like the Russia-Ukraine war on clean energy markets. Its findings emphasise the resilience of green assets as a safe haven against geopolitical risks, a crucial consideration for investors and policymakers aiming to mitigate energy-related uncertainties.

4.8. Co-Authorship Networks in Energy Market and Renewable Energy Research

The co-authorship network visualized in the analysis of 21 countries reveals the intricate web of global collaborations shaping the research landscape of energy markets and renewable energy. Figure 8 shown the co-occurrence of co-authorship using full counting method. The results indicate

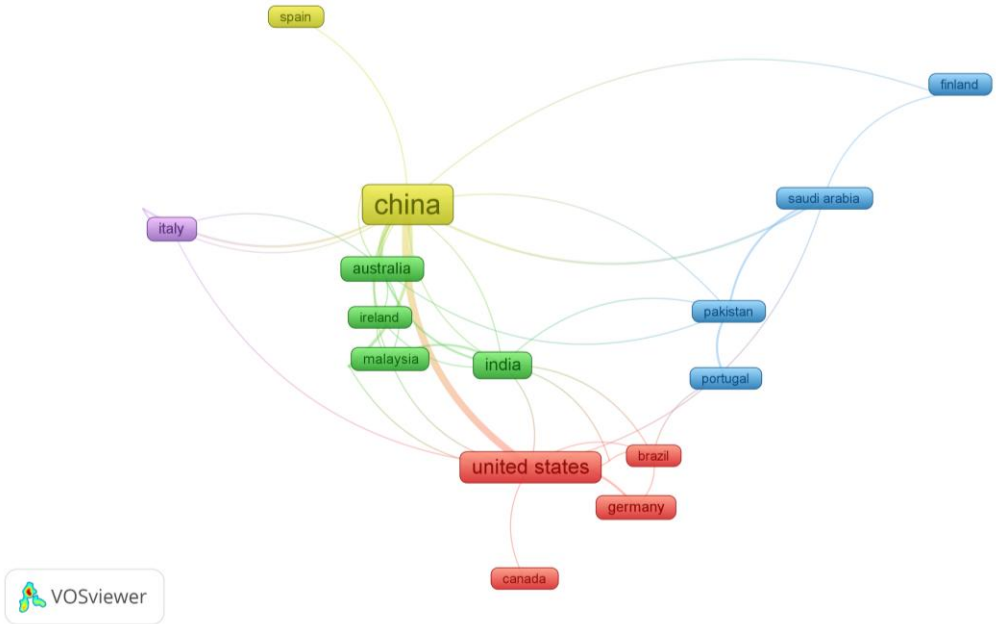

Fig 8. Co-Authorship between countries

there are 21 countries that meet the threshold out of 70 countries. China and the United States, currently the most influential nodes in the network, are poised to maintain their leadership roles in driving global research collaborations. As the largest producers and consumers of renewable energy technologies, these countries continue to attract partnerships from other nations. According to Kut and Pietrucha-Urbanik (2023) and Kristia, K., & Rabbi, M. F. (2023), China's substantial investments in renewable energy manufacturing and deployment, coupled with its active role in international research initiatives, ensure its centrality in the network. Similarly, the United States, with its world-class research institutions and innovation ecosystems, will remain a crucial partner for countries aiming to advance renewable energy integration into energy markets.

The regional clusters that dominate the current network are also likely to grow stronger and more specialized. The Asia-Pacific cluster, centred around China, India, and Malaysia, will increasingly focus on addressing energy access challenges, integrating renewable energy into growing economies, and advancing decentralized energy systems. Meanwhile, Europe, represented by countries such as Germany, Denmark, and Finland, will continue its focus on smart grid technologies, energy efficiency, and innovative market mechanisms.

The nature of collaborations is also likely to evolve, becoming increasingly interdisciplinary as researchers address the complex challenges of renewable energy integration. Countries like Germany and Finland are already pioneering innovations in blockchain-based energy trading, artificial intelligence for energy optimization, and IoT-enabled smart grids. Policy alignment will also play a significant role in shaping future co-authorship networks. Global agreements such as the Paris Accord and regional frameworks like the European Green Deal will drive collaborative research on regulatory harmonization, carbon pricing, and renewable energy market integration (Adelekan *et al.*, 2024). These efforts will encourage partnerships between developed and developing nations, fostering a shared vision for sustainable energy transitions.

4.9 Future Trends in Research Themes: Insights from Colour Clusters in Energy Market and Renewable Energy Studies using the all-keywords co-occurrences.

Figure 9 shows the co-occurrences using all keywords by the full counting method. There are 38 keywords that meet the threshold out of 1816 keywords after the limitation of minimum number of 10 keywords occurrences. The co-occurrence map of keywords in energy market and renewable energy studies provides a rich visualization of thematic research areas, grouped into distinct colour clusters. Each cluster: red, green, blue, and yellow—represents a core dimension of the field, illustrating the interconnectedness of technological, policy, economic, and sustainability-oriented themes. The red cluster, dominated by terms such as renewable energies, power markets, energy trading, and blockchain, reflects the significant influence of technological innovations on the transformation of energy systems. This cluster highlights the ongoing focus on integrating advanced technologies into energy markets to enhance efficiency and decentralization. The identified red clusters in the VosViewer map—such as those focusing on energy savings, renewable energy behaviour, and market adaptation strategies—are further reinforced by empirical studies. For instance, Tampakis *et al.* (2017) emphasized the importance of public perception, willingness to pay, and state subsidies for increasing the adoption of renewable energy technologies, particularly in island settings like Andros, Greece. This aligns with the cluster on "renewable energy adoption and policy support." Similarly, Drosos *et al.* (2019) investigated industrial customer satisfaction in the natural gas sector, highlighting the role of service quality and stakeholder engagement—elements that intersect with our findings on market-driven innovation and the user-centric transition to renewable energy. These studies validate the bibliometric clusters and demonstrate how citizen engagement and market adaptation policies are integral to accelerating energy transitions.

Blockchain technology, for example, is poised to revolutionize energy trading by enabling secure, transparent, and decentralized platforms that empower consumers and producers alike. Similarly, smart power grids and microgrids are gaining attention for their potential to improve energy resilience and efficiency, particularly in urban centers and regions with unreliable centralized grids (Vergados *et al.*, 2016). Future research in this cluster will likely delve into optimizing these systems for scalability and economic viability, exploring the use of game theory, stochastic modeling, and algorithms to address operational uncertainties and profitability challenges. According to Hassan *et al.* (2024a), as energy markets grow more complex, technological innovations will play an increasingly pivotal role in reshaping their structure and functionality.

The green cluster, centred on terms like energy policy, sustainable development, and renewable energy markets, underscores the importance of policy frameworks and sustainability in guiding the renewable energy transition. This cluster reflects the critical role of governance in shaping market structures and incentivizing renewable energy adoption. Policies that balance economic growth with environmental sustainability, such as carbon pricing mechanisms, renewable energy subsidies, and investment incentives, are expected to dominate future research. The interplay between climate change mitigation and energy market dynamics will also drive studies on the socio-economic impacts of energy transitions, particularly in addressing greenhouse gas emissions and aligning with global sustainability goals. According to Renné (2022), as countries strive to achieve ambitious net-zero targets, research in this area will explore how policy innovations can foster equitable and resilient energy systems while attracting private investments.

Moreover, the findings of this bibliometric analysis underscore the critical need to align renewable energy policies with broader climate change mitigation and adaptation frameworks. As climate scenarios increasingly predict extreme weather events, including intensified droughts and variability in precipitation, adaptation measures become imperative to complement mitigation efforts. The integrated management approaches highlighted in recent literature, such as those demonstrated by Sebos *et al.* (2016) and Nydrioti *et al.* (2024), emphasize how incorporating climate projections (RCP scenarios) into resource management strategies significantly enhances urban resilience to climate variability and water scarcity. These strategies include advanced technological solutions, infrastructure investment, and governance improvements aimed at simultaneously reducing emissions and enhancing adaptive capacity.

The blue cluster, characterized by terms such as renewable energy resources, solar energy, and wind power, focuses on the technical and resource-based aspects of renewable energy integration. This cluster emphasizes the ongoing challenges and opportunities associated with transitioning from fossil fuels to cleaner energy sources. As solar and wind power continue to dominate the renewable energy landscape, future research will likely address the technical challenges of integrating these intermittent resources into existing grids. Hybrid energy systems, which combine multiple renewable sources with

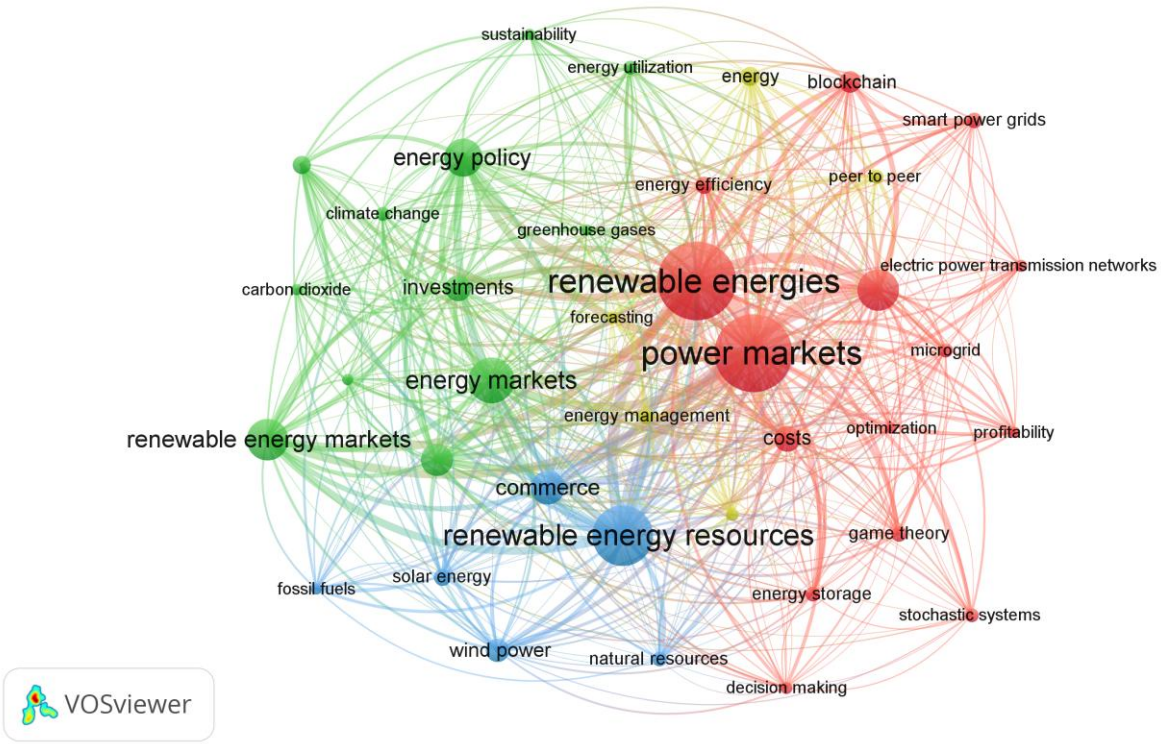

Fig 9. All-keywords co-occurrences

advanced storage technologies, will be a focal point for ensuring grid stability and reliability (Kiasari *et al*., 2024). This cluster highlights the intersection of resource optimization and economic modeling, which is critical for ensuring a smooth transition to a low-carbon economy.

Together, these clusters reveal a dynamic and interconnected research landscape, where technological advancements, policy frameworks, and resource optimization converge to shape the future of energy markets and renewable energy systems. The red cluster points to the transformative potential of digital technologies and decentralization, while the green cluster emphasizes the socio-economic and policy dimensions of the energy transition. The blue cluster complements these themes by focusing on the technical and resource-based challenges of integrating renewables into energy systems.

4.10 Insights Terms (title and abstract) of renewable energy and energy market from Colour Clusters in Energy Market and Renewable Energy Studies

The term co-occurrence map in Figure 10, provides a vivid representation of interconnected research themes in renewable energy markets, grouped into distinct colour clusters. The counting method is full counting, with 15 minimum number occurrences. Only 82 terms meet the threshold, out of 5847 terms. The red cluster, characterized by terms such as blockchain, microgrid, peer-to-peer energy trading, and prosumer, emphasizes the transformative role of technological innovations in decentralizing energy markets. This cluster signifies the growing interest in distributed energy systems, where individuals and small-scale producers, often referred to as prosumers, take an active role in generating and trading energy. Technologies like blockchain are pivotal in enabling secure and transparent peer-to-peer energy trading platforms, reducing reliance on centralized energy suppliers (Esmat *et al*., 2021; Wongthongtham *et al*., 2021). In the future, research will likely delve deeper into how these technologies can be scaled, addressing challenges such as cybersecurity, data privacy, and interoperability. According to Hamidieh and Ghassemi (2022), the microgrids, a key component of decentralized systems, are also expected to gain attention for their ability to enhance energy resilience, particularly in regions prone to grid disruptions or lacking centralized infrastructure.

The green cluster centers around terms like renewable energy market, policy, investment, and risk. This cluster highlights the crucial role of policies and market mechanisms in driving renewable energy adoption. As renewable energy technologies mature, the focus is shifting toward creating efficient and inclusive markets that encourage investments while managing risks. According to Bento *et al.* (2020), policymakers are likely to explore mechanisms such as auction-based pricing, feed-in tariffs, and carbon credits to ensure market stability and attract private sector participation. The alignment of renewable energy initiatives with global sustainability goals, such as the United Nations' Sustainable Development Goals (SDGs), will remain a key area of exploration (Hernandez *et al*., 2020). As renewable energy markets grow, the interplay between policy, investment, and sustainability will define the research landscape, offering insights into how markets can balance profitability with environmental and social equity.

In the blue cluster, terms like uncertainty, value, and profit reveal the economic dimensions of renewable energy markets. This cluster reflects a growing awareness of the financial complexities inherent in transitioning to renewable energy. Researchers are increasingly focused on modeling tools that can forecast market behaviour under different policies and technological scenarios. These tools are essential for addressing uncertainties related to renewable energy variability, price fluctuations, and long-term investment returns. Studies in this area will also explore strategies for managing financial risks, such as insurance schemes, hedging, and innovative financing

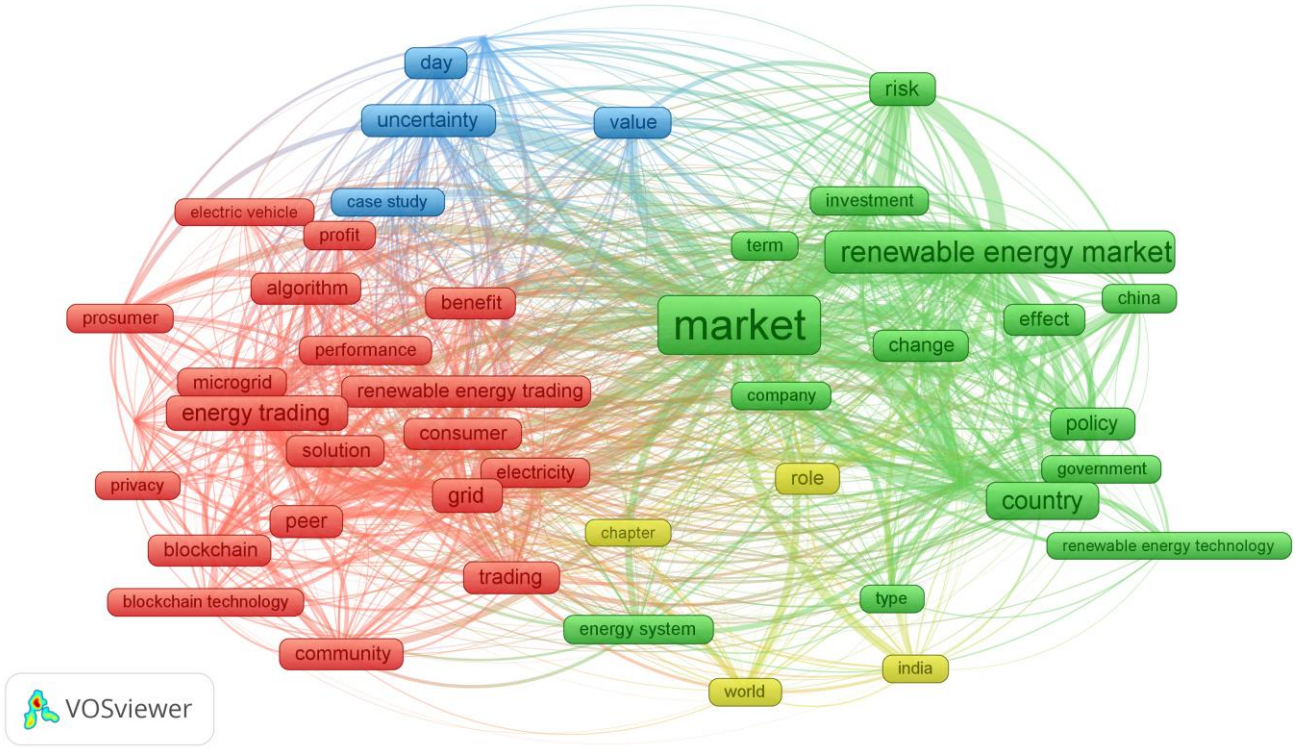

Fig 10. Term co-occurrences

mechanisms. As renewable energy markets expand, ensuring profitability for investors while keeping energy costs affordable for consumers will be a central challenge (Jacobs, 2021). This balance between economic viability and consumer access will shape future research, guiding policymakers and industry stakeholders in making informed decisions.

The yellow cluster, which includes terms such as renewable energy resources, energy system, and India, focuses on the integration of renewable energy into broader energy systems. This cluster underscores the importance of tailoring renewable energy strategies to specific regional and national contexts. For instance, countries like India, with diverse energy needs and significant renewable energy potential (Mohamad and Ab-Rahim, 2024), serve as case studies for how renewable resources can be optimized within complex socio-economic environments (Goyal, 2021). Future research will explore the technical and economic challenges of integrating diverse renewable energy sources, such as wind, solar, and geothermal, into both centralized and decentralized systems. System-level optimization, including hybrid models that combine multiple energy sources, will become a critical area of focus. These studies will address the intermittency of renewables, ensuring that energy systems remain stable and reliable even as renewable penetration increases.

The interconnected nature of these clusters' points to a future where interdisciplinary collaboration is essential. The technological advancements highlighted in the red cluster must align with the policy and market frameworks of the green cluster to achieve practical implementation. Similarly, the economic insights from the blue cluster must guide the technical integration efforts in the yellow cluster, ensuring that renewable energy systems are both feasible and sustainable. By bridging these themes, researchers can address the multifaceted challenges of the renewable energy transition, paving the way for a future where energy systems are not only efficient but also equitable and resilient.

6. Conclusion

In conclusion, this bibliometric analysis has provided an extensive examination of the research landscape in renewable energy and energy markets, highlighting the trends, global contributions, emerging themes, and collaborative networks that shape this rapidly evolving field. By analysing publication patterns and thematic clusters, the study sheds light on the future trajectory of renewable energy research and its integration into global energy markets.

This bibliometric study's key novelty lies in its comprehensive integration of thematic keyword mapping, future trend forecasting, and country-level research contributions to distinctly outline the trajectory and innovation dynamics within renewable energy markets. Additionally, the explicit identification of underexplored regions and topics provides actionable insights for researchers, policymakers, and industry stakeholders, positioning this analysis as an essential resource for understanding future developments in the renewable energy market. The emphasis on recent publications (2023–2024) further underscores the timeliness and relevance of this analysis, highlighting emerging research directions that align with global sustainability goals.

The findings emphasize the transformative potential of technological innovations, particularly in decentralizing energy systems. Technologies such as blockchain, microgrids, and peer-to-peer trading platforms are emerging as pivotal tools in reshaping energy markets. These innovations promise to enhance efficiency, resilience, and transparency, fostering decentralized energy generation and trading. Future research is expected to address the scalability of these technologies, focusing on challenges such as cybersecurity, interoperability, and data management. As these technologies mature, they will redefine the structure and functionality of energy markets, creating new opportunities for collaboration between technologists, policymakers, and consumers.

Policy frameworks and sustainability remain central to the renewable energy discourse. The role of governance in shaping market dynamics and incentivizing renewable energy adoption is increasingly recognized. Future studies will likely explore innovative market mechanisms, such as carbon pricing, renewable energy subsidies, and auction-based pricing, to attract private investments while ensuring market stability. Research in this area will also delve into the socio-economic impacts of energy transitions, addressing equity, inclusivity, and environmental sustainability. As nations strive to meet ambitious net-zero targets, aligning renewable energy policies with global sustainability goals will become a critical area of inquiry.

Economic dimensions of renewable energy adoption, particularly financial viability and market uncertainties are gaining attention. Researchers are increasingly focused on developing advanced economic modeling tools to forecast market behaviour and mitigate financial risks. Future research will explore strategies to balance investor profitability with consumer affordability, ensuring that renewable energy transitions are both economically viable and socially inclusive. Regional contexts also play a vital role in renewable energy integration. Strategies tailored to the specific socio-economic and geographic conditions of regions like India, Africa, and Latin America are essential for optimizing renewable energy systems. Future studies will prioritize the development of hybrid energy systems that combine multiple renewable sources to address the intermittency of solar and wind power. System-level optimization will be critical to ensuring stability and reliability as renewable energy penetration increases globally.

Despite its comprehensive scope, this study is not without limitations. The analysis relies heavily on data from Scopus and Web of Science, which may exclude relevant studies indexed in other databases. Additionally, while bibliometric analysis provides a quantitative overview, it does not fully capture the qualitative depth of research contributions. Future studies could address these limitations by incorporating a broader range of databases and employing mixed method approaches to provide a more nuanced understanding of renewable energy research. Therefore, this analysis highlights the dynamic and interconnected nature of renewable energy research. Technological advancements, policy innovations, and economic insights must converge to address the multifaceted challenges of transitioning to sustainable energy systems. By fostering interdisciplinary collaboration and integrating regional perspectives, future research can pave the way for energy systems that are efficient, equitable, and resilient, contributing significantly to global sustainability goals.

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