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Using VOSviewer for Renewable Energy Literature Analysis: Mapping Technology and Policy-Related Research

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Abstract
This article explores using VOSviewer for literature analysis in the context of renewable energy, with a specific focus on mapping research related to technology and policy. The data, drawn from major scientific databases such as Scopus and Web of Science, encompasses publications discussing the development of renewable energy technology and the policies that support its implementation. Leveraging VOSviewer, this study visualises the collaboration network between researchers, institutions, and countries and identifies the evolution of critical topics in renewable energy literature. Keyword co-authorship and co-occurrence analysis are employed to discern global trends in this research. The results of this study provide profound insight into the relationship between renewable energy technology development and the policies that shape its implementation, thereby indicating opportunities for collaboration and innovation in clean energy. This study is poised to be an inspiring reference for policymakers and researchers, offering a comprehensive understanding of the global dynamics of renewable energy research and igniting the potential for transformative collaboration and innovation in the field.

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1. Introduction
Renewable energy has taken centre stage in global energy transition discussions, driven by the urgent need to curb carbon emissions and reduce our reliance on fossil fuels. Sustainable energy sources such as solar, wind, and bioenergy are increasingly being seen as solutions to our pressing environmental and energy challenges (Hussain et al. 2017; Erdiwansyah et al. 2021; Amjith and Bavanish 2022; Azarpour et al. 2022). However, it's not just about technological advancements. Equally critical are the policies supporting adopting and implementing these renewable energy solutions, which are pivotal in accelerating the shift towards a low-carbon economy. This underscores the growing relevance of research that examines the intricate relationship between renewable energy technologies and the policies that drive their implementation (Sovacool et al. 2020; Ahmad et al. 2024; Bakhsh et al. 2024). Over the past few decades, there has been a substantial surge in scientific publications that explore renewable energy technologies and policies (Mahidin et al. 2020; Hötte et al. 2021; Nica et al. 2024).

Researchers from diverse fields have contributed invaluable insights into the development of these technologies and the pivotal role of policy in fostering innovation and adoption (Foxon and Pearson 2008; Bogers et al. 2018; Erdiwansyah et al. 2022). However, the sheer volume of this research often poses a challenge, making it difficult for researchers to discern trends, collaboration patterns, and the intricate relationship between technology and policy in the renewable energy landscape. Yet, amidst this complexity, there lies a wealth of opportunities for collaboration and innovation, inspiring hope for a cleaner, more sustainable energy future (Sivaram 2018; Awan 2021; Gani et al. 2023).

Bibliometric analysis is one effective method for large-scale scientific literature mapping (Guillén-Pujadas et al. 2024; Huang and Chen 2024; Mirawati et al. 2024). Using software such as VOSviewer, researchers can visualise collaborative networks between researchers, institutions, and countries and identify emerging topics in renewable energy research (Tamala et al. 2022; Kemeç and Altınay 2023; Mentel et al. 2023; Kut and Pietrucha-Urbanik 2024). VOSviewer allows mapping networks based on co-authorship relationships and keyword co-occurrence, helping to uncover key research trends and focusing on renewable energy technology and policy (Kuzior and Sira 2022; Tundys and Wiśniewski 2023; Li et al. 2024). This article aims to conduct a literature analysis on renewable energy research, focusing on mapping research related to technology and policy. Using VOSviewer, this article will map the global collaboration network and identify emerging research themes related to renewable energy technology development and policies that support its implementation (Guimarães et al. 2023; Al- Janabi et al. 2024; Sahebi et al. 2024). Through this approach, the research will provide deeper insights into the relationship between technological innovation and policy in driving the clean energy transition.

The results of this study are expected to provide more precise guidance for researchers and policymakers in understanding the dynamics of research in renewable energy. By mapping the relationship between technology and policy, this article is expected to help strengthen international scientific collaboration and provide insights that can support more effective policymaking in supporting the global renewable energy transition. The novelty of this article lies in its holistic approach that combines renewable energy technology and policy analysis using VOSviewer. This article maps the development of renewable energy technologies and highlights how related policies influence and support the implementation of these technologies. In addition, this study emphasises the analysis of global collaborations between researchers, institutions, and countries, providing a more comprehensive insight into the interaction between technological innovation and policy development. By mapping the relationship between technology and policy keywords, this article offers a new perspective on understanding the linkages between scientific research and policy formation that have not been widely explored in previous literature. This can provide a basis for policymakers and researchers to develop more integrated strategies for accelerating the clean energy transition.

2. Methodology

This study uses a quantitative approach through bibliometric analysis to review the literature related to renewable energy, focusing on technology and policy. The data used are taken from major scientific databases, such as Scopus and Web of Science, which include scientific publications on renewable energy technology and policies supporting its development and implementation. The search used keywords such as renewable energy technology and energy policy, with a time limit of the last few years, to ensure that the analysis covered the latest developments in this research. The data obtained was extracted in a format suitable for analysis using VOSviewer software. Using co-authorship data, VOSviewer visualised and analysed the collaboration network between researchers, institutions, and countries. In addition, keyword co-occurrence analysis was conducted to identify key themes emerging in research related to

renewable energy technology and policy. Nodes in this network indicate the contribution of a particular entity, while connecting lines illustrate the intensity of collaboration between these entities.

A temporal analysis was also conducted to observe changes in research focus over time, considering the evolution of renewable energy technology and policy topics. The resulting data were then interpreted to provide insights into the relationship between renewable energy technology development and the policies that support it and identify opportunities for international collaboration in this area.

3. Result & Discussion

Fig. 1 visualises a bibliometric network generated using VOSviewer, a tool often used to analyse relationships between keywords or themes in scientific research. In this figure, three primary colour groups (green, blue, and red) represent clusters of keywords or themes frequently appearing in articles related to renewable energy. The green cluster on the left consists of keywords related to renewable energy policy, regional analysis, and interactions between countries. Keywords such as policy, country, India, China, and OECD country indicate a focus on energy policy discussions and the role of specific countries in the transition to renewable energy. Research in this cluster typically focuses on geopolitical, economic, and strategic aspects of renewable energy development in different countries. The red cluster on the right focuses on developing renewable energy technologies. Keywords such as solar energy, catalyst, water splitting, and synthesis indicate that this cluster includes scientific and engineering research on innovation in renewable energy technologies, especially in photocatalysis, water splitting, and energy storage through batteries and supercapacitors. This suggests that this cluster includes experimental research to improve the efficiency of renewable energy technologies.

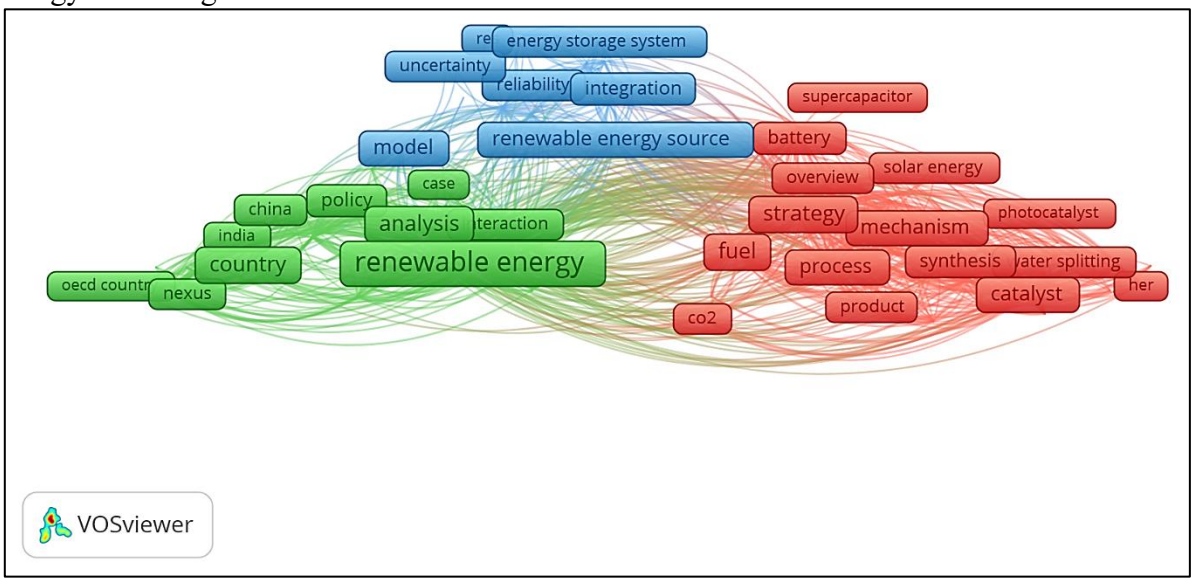

Fig. 1. Visualization of bibliometric networks of relationships between keywords and themes in research

Meanwhile, the blue cluster at the top illustrates themes related to renewable energy sources, integration, reliability, and energy storage systems. This theme leads to discussions about how renewable energy can be integrated into existing energy systems, focusing on the reliability and uncertainty of such integration. The research included in this cluster is often interdisciplinary, involving modelling and simulation analysis to understand the impact of renewable energy integration on conventional energy networks. Compared to previous studies,

this visualisation provides a more focused picture of renewable energy's latest technological and policy developments. Previous studies, such as those conducted in the early 2010s, focused more on general discussions of the benefits and challenges of renewable energy without any in-depth discussion of specific technologies, as shown in the red cluster. This indicates that the focus of renewable energy research has shifted from advocacy and theory to technological innovation and practical implementation.

Fig. 2 results from a bibliometric visualisation generated with VOSviewer, which groups keywords based on their relationship and intensity of use in scientific research related to renewable energy. Unlike the previous figure, this visualisation also includes temporal information with a colour scale that shows the development over time, from early 2020 (blue) to around 2021 (yellow). This temporal information allows us to see the evolution of the focus of renewable energy research during this period. In the green cluster focusing on renewable energy policy, keywords such as policy, country, and nexus have been used more since 2020 (blue to green). This indicates that policy issues and cross-country analysis were the focus of renewable energy research at the beginning of the period, especially in countries such as China and India, as mentioned in the figure. Older research tends to focus on macro aspects, such as how large countries play a role in energy transition.

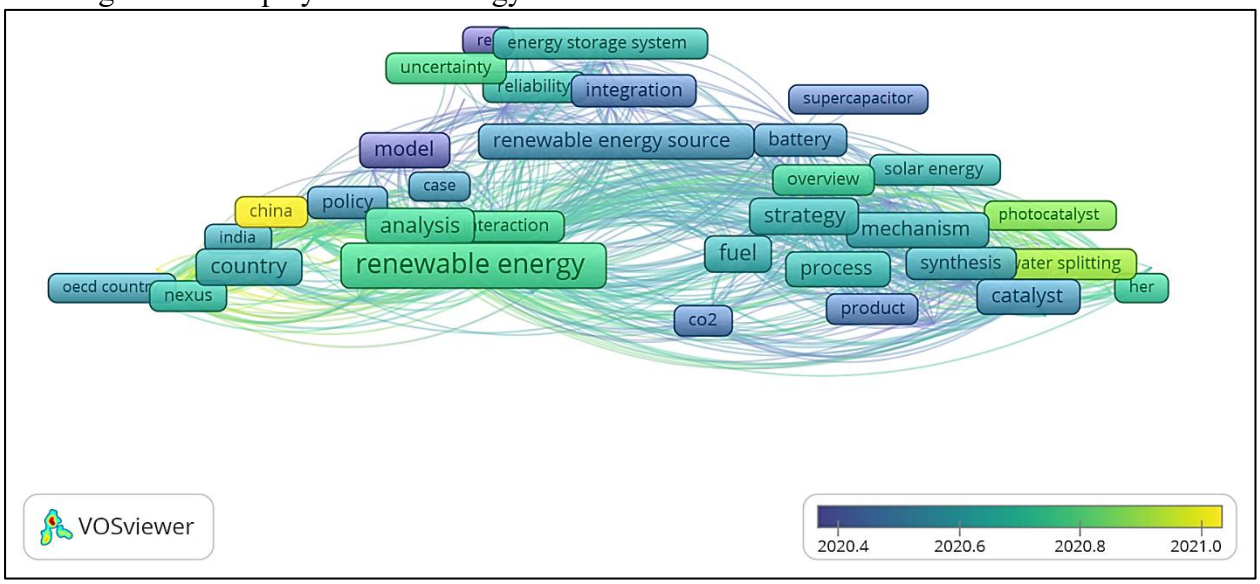

Fig. 2. Relationship and intensity related to renewable energy

The red cluster, which contains technology-related keywords such as water splitting, catalyst, and photocatalyst, appears to be gaining more attention as 2021 approaches (yellow). This shows that scientific research on these technologies has increased significantly in recent years, aligning with the development of renewable energy technologies. More recent research also explores innovative technology that enables renewables, such as solar energy and energy storage methods, to become more efficient. The blue cluster, which includes keywords such as energy storage system, integration, and reliability, shows an increase in interest in these topics from around mid-2020 to early 2021 (changing from blue to green). This indicates increased attention to the technical challenges of integrating renewables into the existing energy grid. Topics such as system reliability and energy storage are becoming more critical due to the need to overcome technical obstacles in the clean energy transition. Compared with research before 2020, current renewable energy research focuses more on practical energy storage and technology implementation. Previously, research focused more on policy development and general feasibility studies. Still, recent trends show a shift towards concrete technical solutions, such as energy storage and catalyst development for photocatalytic reactions. This reflects the

evolution of research focus from theoretical to experimental phases and practical implementation.

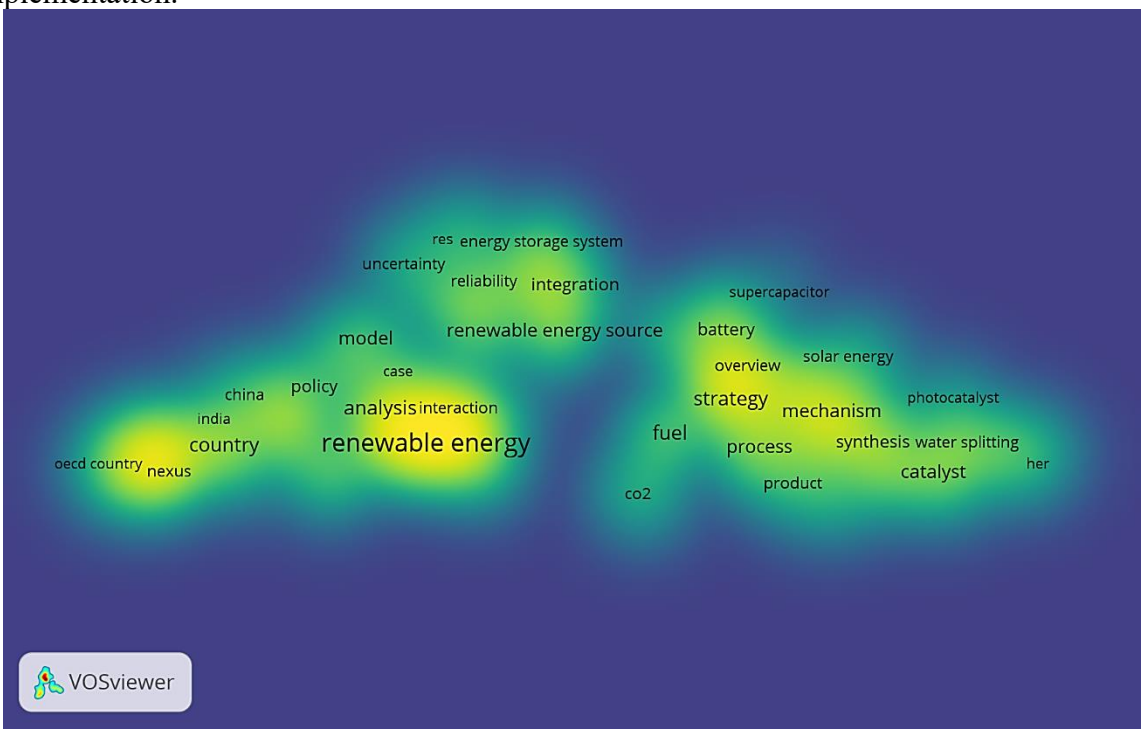

Fig. 3. The results of the bibliometric visualisation of the density of the articles in this study.

Fig. 3 is the result of bibliometric visualisation using VOSviewer with density visualisation. In this visualisation, the area with yellow intensity shows the most frequently appearing and most relevant keywords in renewable energy research. In contrast, the green-to-blue areas show keywords that occur less often. Visualisations like this help see the research focus and which areas are most explored. In the centre of the image, the keyword renewable energy appears as the most central keyword. It is coloured bright yellow, indicating that the topic of renewable energy is the most frequently discussed. This is reasonable because all research is related to renewable energy. Supporting keywords around renewable energy, such as policy, country, analysis, and interaction, are also coloured yellow to bright green, indicating that the policy aspect, cross-country analysis, and international interaction related to renewable energy are significant and frequently discussed themes. On the right side of the figure, the technology-related cluster also appears strong with keywords such as catalyst, water splitting, solar energy, and supercapacitor. This area has a yellow-green intensity, indicating that research into renewable energy technologies is also a topic of great interest. This reflects the growing interest in experimental technologies such as using catalysts in splitting water to produce hydrogen and supercapacitors as more efficient energy storage devices.

The left side of the figure shows the topic of policy and geography, with keywords such as country, China, India, and OECD country tending to be in the green to light yellow areas. This shows that research on energy policies in various countries, especially in large countries such as China and India, has considerable significance in the literature. Compared with technology, the focus on these policies is more likely related to cross-country analysis and implementation strategies in large countries. Compared with previous research, this visualisation confirms that the focus of renewable energy research is increasingly segmented between international policy and technology research. In the early 2000s, most renewable energy research focused on the urgency of energy transition and global challenges. However, in more recent studies, we see a more specific focus on policies of particular countries and technological innovations, each of

which is increasingly developing and becoming the centre of attention in various scientific journals.

4. Conclusion

Based on the results of the bibliometric visualisation analysis displayed in several images above, it can be concluded that current renewable energy research has undergone significant diversification, covering various aspects, from international policies to specific technology development. Several main points can be concluded:

a. The keyword renewable energy is the central theme connecting various policy and technology topics. This shows that renewable energy continues to be a significant focus of attention in scientific literature, especially related to global energy transition efforts.
b. Renewable energy research involves cross-country policy analysis with significant countries such as China and India as critical actors. Discussion of energy policies and how countries integrate renewable energy into their strategic plans is one of the central themes that has received widespread attention, as seen in the cluster related to countries and policies.
c. Research on technologies, such as catalysts in water splitting, energy storage technology (supercapacitors), and solar energy, is increasingly becoming a primary focus in current research. This shows significant progress in renewable energy technologies' experimental and innovative aspects to achieve higher efficiency and reliability.
d. Compared to previous renewable energy research that tended to focus on the urgency of energy transition and global challenges, current research is increasingly segmented between policy and technology. The research focus has shifted towards more practical and measurable solutions regarding international policy and the development of new technologies that can support broader renewable energy integration.

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