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Bibliometric Analysis of Renewable Energy Research Trends Using VOSviewer: Network Mapping and Topic Evolution

Irhamni[1], Erlina Kurnianingtyas[1], Muhtadin[2], Bahagia[3], Ahmad Fitri Yusop[4]

[1]Environmental Engineering Department, Institut Teknologi Sumatera, Bandar Lampung, Indonesia
[2]Department of Mechanical Engineering, Universitas Abulyatama Aceh, Aceh Besar, 23372, Indonesia
[3]Department of Environment Engineering, Universitas Serambi Mekkah, Banda Aceh, 23245, Indonesia
[4]Centre for Automotive Engineering, Universiti Malaysia Pahang Al-Sultan Abdullah

Corresponding author: irhamni@tl.itera.ac.id

Abstract
This article presents a bibliometric analysis of renewable energy research trends using VOSviewer software. The study aims to map the collaboration network between researchers, institutions, and countries and to identify the evolution of emerging topics in the field of renewable energy. The data is taken from leading scientific databases covering publications in recent years. The article uses network map visualisation techniques to reveal collaboration patterns and research distribution focused on critical themes like solar, wind, and bioenergy. In addition, the article analyses frequently occurring keywords, helping to identify emerging topic trends. The results of this study are expected to provide insights into the direction of future developments in renewable energy research and encourage increased international collaboration in the field.

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1. Introduction
Renewable energy has become one of the most important research topics in recent decades, along with the increasing need for clean and sustainable energy sources. Climate change, environmental degradation, and the depletion of fossil resources have driven researchers and policymakers to seek alternative, environmentally friendly solutions (Elum and Momodu 2017; Ali et al. 2021; Yi et al. 2023). Renewable energy, such as solar, wind, bioenergy, and hydroelectricity, offers excellent potential to reduce dependence on fossil fuels and minimise negative environmental impacts (Erdiwansyah et al. 2019b, a, 2021). As interest in renewable energy increases, scientific publications grow significantly (Erdiwansyah et al. 2022; Ghazinoori et al. 2023; Al-Shetwi et al. 2024). Research in this field covers various disciplines and involves collaboration across countries and institutions. Therefore, it is essential to understand how this research trend is developing, both in terms of publication volume, collaboration networks between researchers, and the evolution of the topics that are currently the focus (Leahey 2016; Sampaio et al. 2017; Fuentes Barrera et al. 2021). Bibliometric

analysis is one practical approach to obtaining a comprehensive picture of research developments in a scientific field (Dragović et al. 2024; Jin et al. 2024; Mishra 2024).
VOSviewer is a widely used software for bibliometric analysis that visualises network maps and analyses topic evolution. (Guo et al. 2024; Yang et al. 2024; Zhu et al. 2024). It can identify collaboration patterns, keyword frequencies, and relationships between entities in a research network, allowing researchers to gain deeper insights into the direction of scientific development (Chen et al. 2019; Cai 2023; Gu et al. 2024). In the context of renewable energy research, this analysis helps identify critical actors in the field and observe shifts in research focus over time. This article aims to conduct a bibliometric analysis of renewable energy research trends using VOSviewer. This research focuses on mapping the collaboration network between researchers, institutions, and countries and analysing the evolution of emerging topics in renewable energy. Through network map visualisation, this article will reveal the patterns of scientific collaboration and the themes that dominate and evolve (Coccia and Wang 2016; Sheng et al. 2023).
This research is expected to contribute significantly to understanding the direction of future renewable energy research developments. By mapping global trends and collaborations, the results of this study can be used as a basis for researchers and policymakers to strengthen international cooperation and direct research to the most relevant areas to address increasingly complex energy and environmental challenges. The novelty of this article lies in the use of VOSviewer software to comprehensively map the collaboration network and evolution of renewable energy research topics, which have not been widely reviewed in previous literature. In addition, this article focuses on identifying keyword trends and explores the relationships between researchers and institutions globally, which provides new insights into how international collaborations develop in this field. Researchers in this study used bibliometric analysis and network visualisation to understand better how renewable energy research changes over time. This should make it easier to find ways to work together and speed up the development of new ideas in the clean energy field.

2. Methodology

This study uses a quantitative approach through bibliometric analysis to identify trends in renewable energy research. The data used in this study are taken from leading scientific databases, namely Scopus and Web of Science. These databases were chosen because they provide access to extensive scientific publications and include journals with high reputations. This study contains articles, conference proceedings, and literature reviews published over the past 10 years, focusing on publications that have keywords related to renewable energy, such as solar energy, wind, bioenergy, and hydroelectricity.
The data collection process used relevant search keywords, such as renewable energy, solar energy, wind energy, and bioenergy, in the database's titles, abstracts, and keywords of articles. The data taken were then extracted into a format that could be processed using VOSviewer software. The total publications retrieved were analysed in frequency, annual growth, and geographic distribution to identify critical patterns and trends in renewable energy research. Once the data was collected, VOSviewer was used to map the collaboration network between researchers, institutions, and countries based on the number of co-authorships in the analysed publications. This software allows the visualisation of interactions between entities in the form of a network map, where the size of the nodes indicates the intensity of collaboration, and the connecting lines indicate the strength of the relationship between entities. In addition, a keyword co-occurrence analysis was performed to see the evolution of research topics and identify the main themes developing in renewable energy.
This analysis also observes the temporal distribution of frequently occurring keywords to illustrate changes in research focus over time. Mapping the evolution of topics is done by

grouping keywords by specific periods, which allows the identification of new and rising trends in the renewable energy field. Finally, the analysis's results are interpreted to provide insight into global collaboration patterns and changes in research focused on renewable energy. This method's results are expected to provide a comprehensive view of the direction of research development in renewable energy and strengthen international collaboration in clean energy research.

3. Result & Discussion

The VOSviewer software produced a network visualisation of a keyword map in Fig. 1. VOSviewer is often used for bibliometric and citation analysis, allowing users to map the relationships between research topics. This figure displays several critical terms related to renewable energy research, with the connecting lines showing the connections between the issues or co-occurrences in academic literature. Terms such as “renewable energy,” “trend,” “research,” “review,” and “energy” dominate this map and appear to be the focus of the analysed literature. Different colours indicate closely related groups or clusters representing specific research themes.

The red, green, and blue clusters in this map indicate topics that are closely related to each other. For example, the red cluster tends to be about research trends and challenges in renewable energy, while the green cluster focuses more on renewable energy integration and research reviews. The blue cluster is more minor, perhaps referring to specific applications in renewable energy. These patterns can help researchers identify future research directions, gaps in the literature, or unexplored relationships between concepts in the renewable energy field.

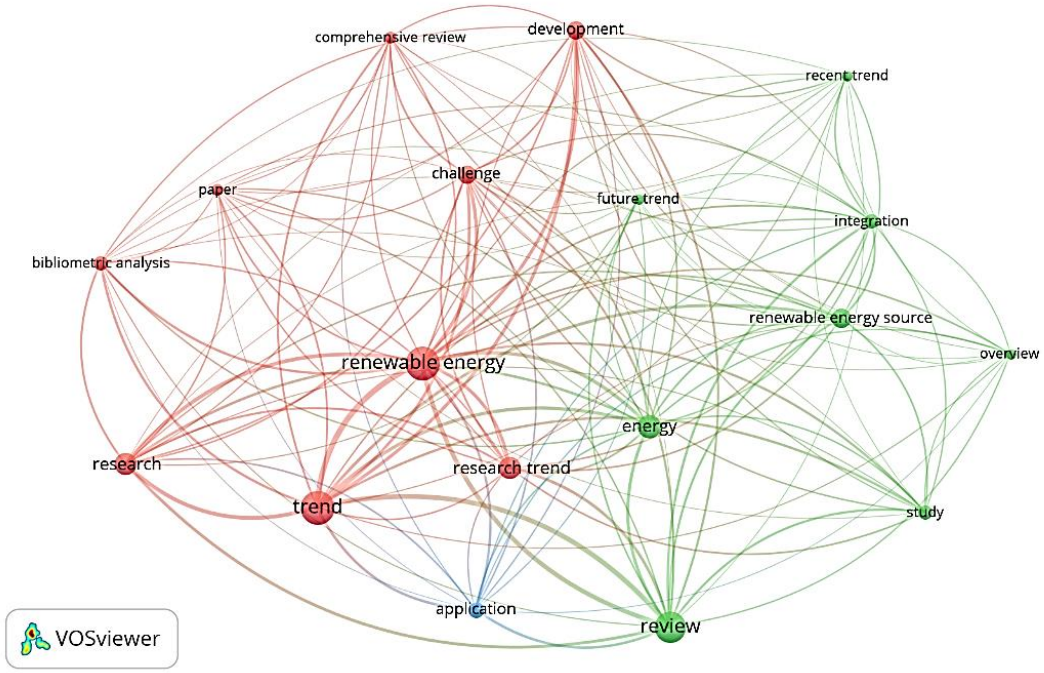

Fig. 1. Visualization of keyword map network

A bibliometric map visualisation created by VOSviewer, **Fig. 2**, demonstrates trends and connections between keywords related to renewable energy research. The colour bars at the bottom of the figure indicate that the various colours in this visualisation indicate a temporal distribution. Dark blue represents publications around 2020, while yellow indicates more recent topics in 2021. Keywords such as renewable energy, trend, research, and review are at the centre of the network, indicating that these are frequently discussed themes and are closely

related to many other topics in the academic literature. The relationship between “renewable energy” and other issues such as trend, research trend, and review suggests that discussions about renewable energy are focused heavily on research developments and critical reviews of existing studies.

The colour analysis also shows the shift in research focuses over time. Words such as bibliometric analysis and paper, associated with the colour yellow, indicate that recent studies have focused on comprehensive reviews of renewable energy literature. On the other hand, words closer to the colour blue, such as integration and renewable energy source, indicate that research related to the application of renewable energy sources has been discussed earlier, around 2020 to early 2021. This suggests that the research trend is shifting from reviews of practical applications and challenges to more in-depth bibliometric analysis and evaluation. In conclusion, this map provides a clear picture of how renewable energy research topics have evolved and how research focus has shifted from one area to another.

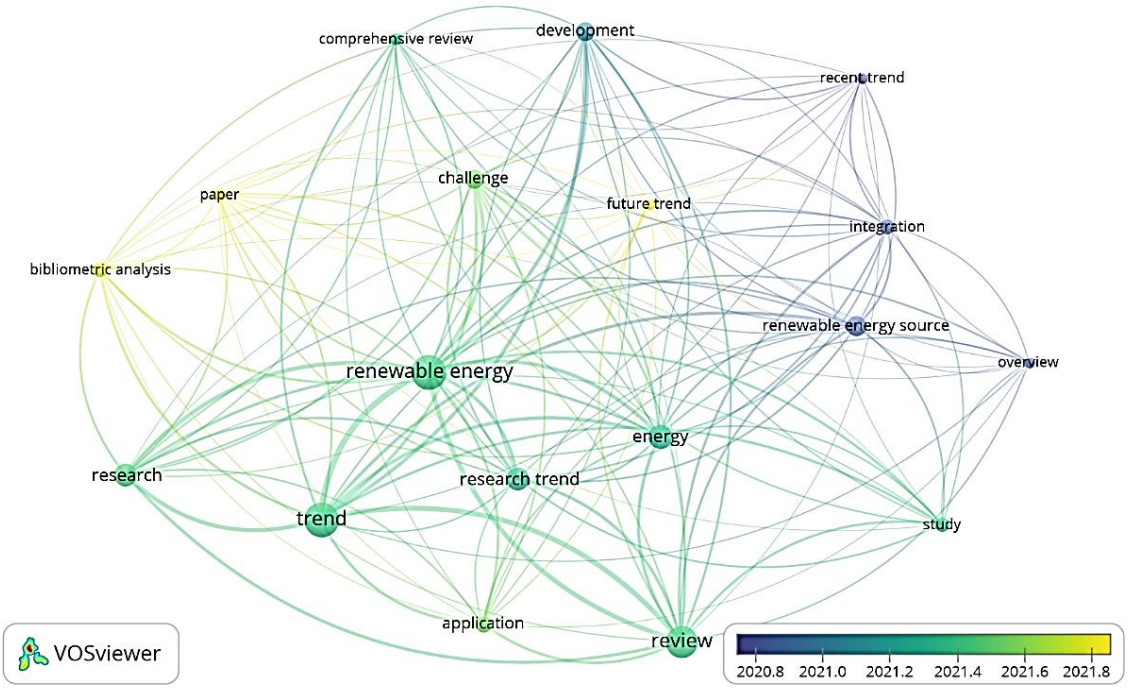

Fig. 2. Bibliometric map visualisation

Fig. 3 is a visualisation of the density map generated by VOSviewer, which shows the density of the most frequently occurring terms related to renewable energy in the literature. In this map, yellow indicates areas with higher term density, meaning keywords often appear together in research or scientific discussions. In comparison, the green and blue colours indicate areas with lower density. Terms such as "renewable energy," "trend," and "review" appear to have a very high concentration (in yellow), indicating that these topics are the focus of attention in renewable energy research.

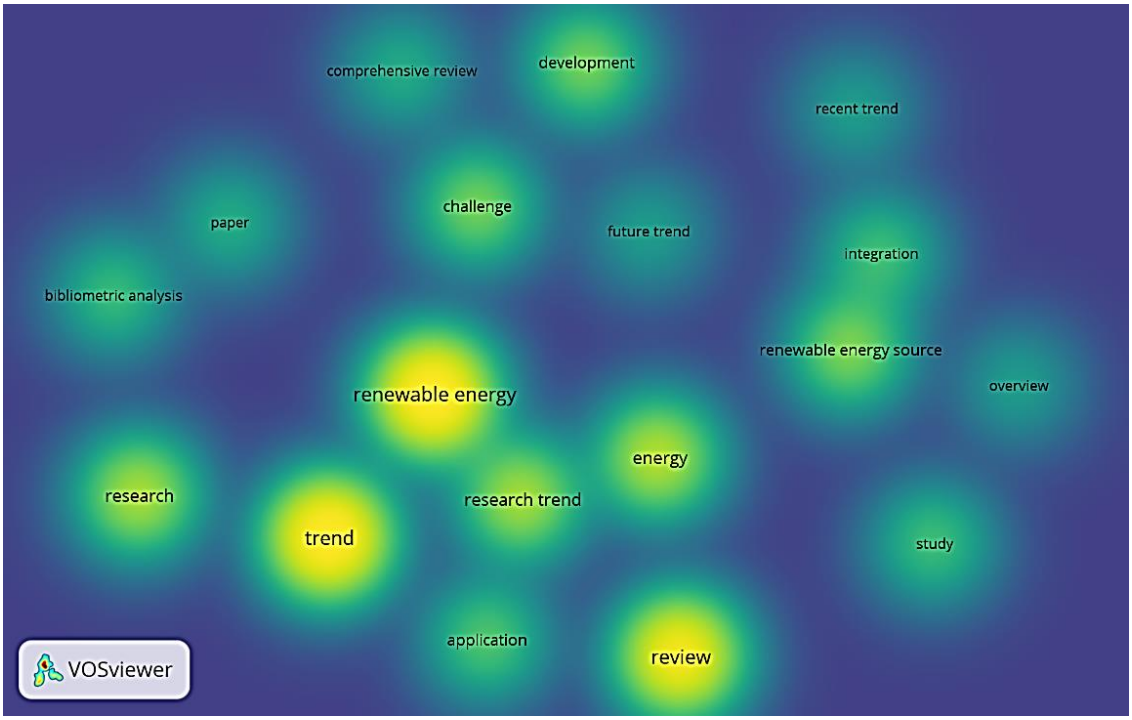

Fig. 3.

Table 1 shows the interrelated data of keyword categories that appear in the bibliometric analysis related to renewable energy research. The table lists various metrics for each keyword category, including coordinate position (X and Y), the cluster in which the keyword is located, the number of links, total link strength, occurrences, and average publication year (Avg. pub. year). Based on this data, the keyword "renewable energy" has the highest number of occurrences, 84 times, with a total link strength of 245. This indicates that this topic is very prominent and closely related to many other keywords in the research network. In addition, the category "trend" also has a high number of occurrences (84 times) and a very significant link strength (237), indicating that trends in renewable energy are one of the frequently discussed topics in recent literature.

Table 1. Relationships between related categories

Categories	X	Y	cluster	Links	Total link strength	Occurrences	Avg. pub. year
Application	0.1007	0.8814	3	15	66	19	2021.5263
Bibliometric Analysis	0.9421	-0.4987	1	15	49	15	2021.7333
Challenge	0.2147	0.4416	1	17	94	25	2021.52
Comprehensive review	0.4687	0.4691	1	15	42	11	2021.3636
Development	-0.1046	-0.567	1	17	89	25	2021.08
Energy	-0.1294	-0.1013	2	17	120	39	2021.3077
Future trend	-0.2706	0.6109	2	14	25	8	2022.125
Integration	-0.707	0.2433	2	16	59	16	2020.875
Overview	-1.0592	0.0979	2	13	26	8	2020.875

Categories	X	Y	cluster	Links	Total link strength	Occurrences	Avg. pub. year
Paper	0.8828	0.3032	1	14	41	11	2021.9091
Recent trend	-0.769	-0.0912	2	14	26	8	2020.625
Renewable energy	0.2518	-0.3319	1	17	245	84	2021.4048
Renewable energy source	-0.6183	-0.2404	2	16	74	27	2020.8889
Research	1.0166	-0.1184	1	16	122	36	2021.4167
Research trend	0.3377	-0.0244	1	15	92	35	2021.3143
Review	-0.2444	0.2805	2	17	183	67	2021.403
Study	-0.7199	-0.6929	2	14	58	16	2021.375
Trend	0.4074	-0.6616	1	16	237	84	2021.3929

Some other categories, such as “review” (67 occurrences) and “research” (36 occurrences), also play an essential role in the renewable energy literature, with a relatively large total link strength. However, some keywords such as “recent trend” and “overview” appear less frequently (only 8 times each), indicating that these topics are less often discussed. The average year of publication also shows a recent trend in this research, with some keywords such as “future trend” indicating a more recent research focus (average year 2022), while some other topics such as “integration” and “renewable energy source” have an earlier average year of publication, around 2020. This suggests that the direction of renewable energy research has shifted from earlier topics to more futuristic and predictive research.

Fig. 1, **2**, and **3** above are bibliometric visualisations, and **Table 1** above shows a close relationship in describing the development and trends of renewable energy research. The first figure shows the network of relationships between keywords in renewable energy research, where the keywords "renewable energy," "trend," and "research" appear as frequently discussed topics. The second figure, which depicts the time distribution and the fact that issues like "renewable energy" and "trend" appear consistently and continuously in research from 2020 to 2021, supports this. The density visualisation in the third figure also strengthens the importance of these keywords, showing that terms such as "renewable energy" and "review" have a very high density, indicating that this is the focus of the literature. Table 1 shows explicitly that "renewable energy" and "trend" have a very high number of occurrences, 84 times each, and solid total link strength, namely 245 and 237, indicating their relationship with many other keywords. Overall, the analysis of the three figures and Table 1 shows that “renewable energy” and “trend” are the focus of recent research, while some topics, such as “future trend,” are developing and indicate the future direction of research in this field.

4. Conclusion

Based on the analysis of the three bibliometric visualisations and Table 1, it can be concluded that "renewable energy" and "trend" are the central core of renewable energy research in recent years. These keywords not only have a high number of occurrences but also have a strong relationship with other topics, such as "research," "review," and "energy," indicating that research in this field focuses on the trend and development of renewable energy in a broad sense. The latest development in this research is seen from the emergence of terms such as "future trend" and "challenge," indicating a new focus on the challenges and future directions of renewable energy. In addition, the temporal distribution in the visualization and tabular data shows that there is a shift in focus from early topics such as “integration” and “renewable energy sources” to more comprehensive reviews and analyses, with more recent

publications focusing on “bibliometric analysis” and “papers.” This indicates that renewable energy research has reached a stage of critical evaluation of existing literature while continuing to explore future challenges. Overall, renewable energy research continues to grow strongly, focusing clearly on research trends, literature evaluation, and preparation for a more sustainable renewable energy future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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