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Bibliometric Analysis Of Green Hydrogen Energy Research Trends In Scopus

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Abstract
The present study uses information from the Scopus database, which has 13,212 papers, to do an extensive bibliometric analysis of research on green hydrogen energy methods. This analysis's goals are to chart the development of research trends in the field of green hydrogen energy, recognize significant contributions, and highlight new areas of inquiry. In order to shed light on the collaborative dynamics and theme growth in this field, the research uses VOSviewer software to show publication trends, co-authorship networks, and keyword co-occurrences. Green hydrogen energy is becoming more and more popular as a sustainable option in the energy industry, as seen by the results, which show a notable rise in publications over the last ten years. Along with important topics that need further investigation, prominent writers, organizations, and nations spearheading this study are recognized. This bibliometric study provides insightful avenues for future research and policy consequences, in addition to helping to clarify the state of the art in green hydrogen energy research today.

Keywords: Bibliometric Analysis; Green Hydrogen Energy; Research Trends; Scopus Database; VOSviewer.

1 Introduction

Green hydrogen is becoming more and more important in the global energy scene as the need to fight climate change and switch to sustainable energy sources grows. Green hydrogen is being hailed as a flexible and sustainable energy source. It is created by electrolyzing water using renewable energy sources including sun, wind, and hydropower. Green hydrogen is a vital component in reaching global decarbonization objectives since, in contrast to current hydrogen production technologies, which often depend on fossil fuels, it provides the potential to considerably cut greenhouse gas emissions and boost energy security. Green hydrogen energy is becoming more and more popular as countries and organizations make commitments to aggressive climate targets. Green hydrogen has a wide range of possible uses, from energy storage and heating to industrial operations and transportation. These uses highlight how crucial it is to do research and develop new ideas in order to create technology that make it easier to produce, store, and use green hydrogen. As a result, researchers studying green hydrogen have received more attention from academic and industry partners, which has caused the body of published literature on the topic to grow quickly.

Comprehensive evaluations that shed light on the trends and patterns in the area of green hydrogen energy are desperately needed, especially in light of the expanding body of research. The quantitative examination of academic literature known as bibliometric analysis is a useful technique for charting the development of scientific inquiry. With this method, researchers may monitor citation trends, identify key publications, and discover author and institution collaboration networks. Moreover, bibliometric analysis may highlight new directions in research as well as areas of rising concern, laying the groundwork for subsequent investigations and guiding policy choices. The Scopus database offers a strong foundation for doing bibliometric analysis because of its broad coverage of peer-reviewed literature in a variety of areas. Through the use of Scopus data, researchers may learn more about the dynamics of research on green hydrogen, such as publishing patterns over time, the distribution of research output geographically, and the identification of influential authors and institutions. Furthermore, the use of tools like VOSviewer to visualize data improves comprehension of intricate correlations found in the literature, making it easier to identify significant clusters and themes.

One of the most important elements in the worldwide shift to sustainable energy systems is green hydrogen energy. Green hydrogen, a sustainable energy carrier that may effectively decarbonize several industries, is generated by water electrolysis fueled by renewable energy sources. Through the use of bibliometric analysis, this literature review synthesizes research trends and breakthroughs in green hydrogen energy from 2015 to 2025, highlighting important topics, seminal publications, and cooperative networks. The purpose of this study is to conduct a bibliometric analysis of research on green hydrogen energy using 13,212 papers that were obtained from the Scopus database on dated 29th December 2024. VOSviewer software will be used in the study to show co-authorship networks, publication patterns, and keyword co-occurrences. The study aims to provide important insights into the current state of green hydrogen energy research by methodically examining this large body of literature. It does this by highlighting the contributions of important authors, institutions, and nations, as well as by identifying recurring research themes and possible areas for future investigation. It is crucial to comprehend the larger context of green hydrogen energy within the global energy transition in order to define the relevance of this study. To prevent the worst effects of climate change, the Intergovernmental Panel on Climate

Change (IPCC) has underlined the need of swift and significant cuts in carbon emissions. In this regard, hydrogen is becoming more widely acknowledged as a vital facilitator of deep decarbonization in a number of industries, such as manufacturing, transportation, and energy production. Green hydrogen has a wider range of applications since it may be used directly as fuel or transformed into ammonia for storage and transportation.

Green hydrogen integration into current energy systems also has the potential to alleviate a number of issues related to the production of renewable energy, most notably the intermittent nature of solar and wind energy. Energy may be transferred and stored by electrolyzing surplus renewable energy to produce hydrogen, which provides a workable way to balance supply and demand. Furthermore, green hydrogen may be very important in hard-to-abate industries like aviation and heavy industrial, where direct electrification might not be as practical. Green hydrogen has a lot of promise, but there are still a lot of obstacles in the way of its widespread use. These include the requirement for infrastructure expansion, the high cost of manufacturing, and the progress of storage and transportation technology. To overcome these obstacles and realize the full promise of green hydrogen as a pillar of the future of sustainable energy, research in these fields is essential.

Numerous disciplines have used bibliometric analysis to evaluate research trends, pinpoint seminal publications, and investigate collaborative networks. Comprehensive bibliometric studies that concentrate just on research related to green hydrogen energy are, however, very rare. By offering a thorough bibliometric analysis of the area, this study aims to close this knowledge gap and advance our understanding of the state of green hydrogen energy research today. This bibliometric study has three goals in mind. Initially, to chart the course of green hydrogen research development throughout time, highlighting significant growth periods and patterns in publication volumes. The second objective is to recognize the top writers, organizations, and nations that are making contributions to this subject while emphasizing the cooperative dynamics that support scientific endeavors. Third, use keyword co-occurrence analysis to examine the literature's topic structure in order to spot recurring themes in the study and any knowledge gaps.

The results of this study will be very helpful to scholars, decision-makers, and industry participants who are trying to understand how the green hydrogen energy market is changing. This study intends to influence future research orientations and policy actions that might promote the progress of green hydrogen technologies by providing a thorough assessment of the research environment. In conclusion, it is impossible to exaggerate the significance of green hydrogen energy in relation to international efforts to mitigate climate change. Bibliometric analysis provides a methodical way to comprehend the patterns, contributions, and gaps in the literature as study in this area continues to grow. The purpose of this study is to use bibliometric analysis to give a thorough evaluation of research on green hydrogen energy, deepening our awareness of its potential and guiding future initiatives to encourage its use.

Current developments in the generation of green hydrogen concentrate on novel materials, effective procedures, and regulatory structures that improve scalability. Proton exchange membrane (PEM) electrolyzers optimized with porous transport layers (PTLs) for enhanced mass transfer and durability are among the significant advancements (DiMeglio et al., 2023). Furthermore, high purity levels (99.994%) have been attained while reducing CO2 contamination by chemical looping hydrogen generation using iron-based oxygen carriers (Blaschke et al., 2023). In order to overcome the intermittent nature of renewable energy sources, electrolysis of renewable energy, especially from solar and wind sources, is gaining popularity as a sustainable way for producing hydrogen (Wang et al., 2023). Additionally, integrated biomass conversion technologies are becoming more and more affordable options for managing waste and converting biomass into electricity (Awoegbemi et al., 2023). All things considered, these developments point to a bright future for the widespread use of green hydrogen, even while obstacles like cost and environmental effects still exist (Sharma et al., 2023).

Green hydrogen generation becomes far more efficient and cost-effective when renewable energy sources are included. For electrolysis systems to maximize hydrogen generation, a more stable energy source is made possible by using solar and wind power. Important conclusions consist of:

(a) Cost Reduction

- The cost advantages of wind turbines (WTs) are highlighted by the fact that WTs may manufacture hydrogen at a rate of USD 0.55/kg, while photovoltaic (PV) systems yield USD 1.5/kg (Рамадан & Gabbar, 2023).
- According to Ikuerowo et al. (2023), the levelized cost of hydrogen (LCOH) from wind energy varies from 5.3 to 9.29/kg, but LCOH from alkaline water electrolyzers (AWE) is between 7.49 and 7.49 and 7.59/kg.

(b) Efficiency Improvements

- Electrolyzers and renewable energy sources together may cut emissions and increase energy efficiency by 11.5% (Hai et al., 2023).
- Direct linking electrolyzers and renewable energy sources reduces system losses and boosts production efficiency (Salam et al., 2023).

Notwithstanding these benefits, obstacles including the sporadic nature of renewable energy sources and the need for sophisticated energy management systems still need to be addressed for broad implementation. Optimizing the potential of green hydrogen generation requires addressing these concerns.

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One of the most important ways to achieve sustainable energy systems and lower carbon emissions is via the use of green hydrogen energy. Green hydrogen provides a clean substitute for fossil fuels since it is produced using renewable energy sources like sun and wind, and it doesn't create any harmful pollutants throughout the process (Maka & Mehmood, 2023; Elshafei & Mansour, 2023). It is a flexible energy carrier with potential uses in a variety of industries, such as electricity generating, heating, and transportation (Pantskhava & Jishkariani, 2023). Nevertheless, obstacles including exorbitant manufacturing costs, inadequate infrastructure, and investment uncertainties impede its extensive integration (Zhou et al., 2022). In addition to international cooperation to create standards and a strong hydrogen economy, a thorough strategy addressing these obstacles is necessary to fully exploit its advantages (Monye et al., 2023).
Global interest in green hydrogen as a renewable energy source is expanding, according to recent bibliometric studies of research on the topic. Research has looked at important nations and institutions, major research topics, and publishing patterns. Hydrogen generation, storage, electrolysis, and the hydrogen economy are important research areas (R. Raman et al., 2022). The International Journal of Hydrogen Energy is a well-known publishing venue, and the United States and China emerge as the top contributors (Jasgurpreet Singh Chouhan, 2021). Scientific attention is focused on electrolysis technologies, specifically on alkaline and proton exchange membrane electrolyzers. According to Pablo Fernández-Arias et al. (2023), Europe has a significant commitment to green hydrogen research and development. According to L. Camargo et al. (2022), these research demonstrate the growing significance of green hydrogen in combating climate change and accomplishing sustainable energy objectives.
The bibliometric analytic approach used, the study's findings, and their implications for future research and policy in the subject of green hydrogen energy are all covered in the parts that follow in this publication. In addition to highlighting the importance of green hydrogen as a crucial element of the shift to a sustainable energy future, our analysis aims to provide insights that might help progress this exciting field of study.

2 Methodology

One of the biggest databases of peer-reviewed abstracts and citations is Scopus, which covers a broad spectrum of fields such as science, technology, health, social sciences, and the arts and humanities. Researchers may get a multitude of information from Scopus, which offers extensive coverage of scientific publications. This includes journal articles, conference papers, patents, and more. Users may examine citation networks in a variety of sectors and evaluate the effect of research thanks to its comprehensive citation monitoring features. In order to find relevant papers especially on green hydrogen energy for this research, a methodical search approach was used to search the Scopus database. To guarantee a thorough and focused search, a mix of keywords and Boolean operators were used. The main search phrase that was utilized was "Green Hydrogen Energy," and Figure 1 shows that all relevant research was found using just this keyword. The search parameters were restricted to papers released between 2015 and 2025, which corresponds to a critical era for the growing acceptance of hydrogen as a feasible energy source and the ensuing surge in research endeavors during this time. To ensure uniformity in the analysis, the search was further limited to English-language articles. Figure 1 shows the first search results found in Scopus for the combination of keywords "green AND hydrogen AND energy." 13,212 documents in all spanning a broad variety of research topics linked to the generation, storage, and use of green hydrogen energy were obtained. Document type, publication year, and authors are just a few of the criteria that may be used to further tailor the results.

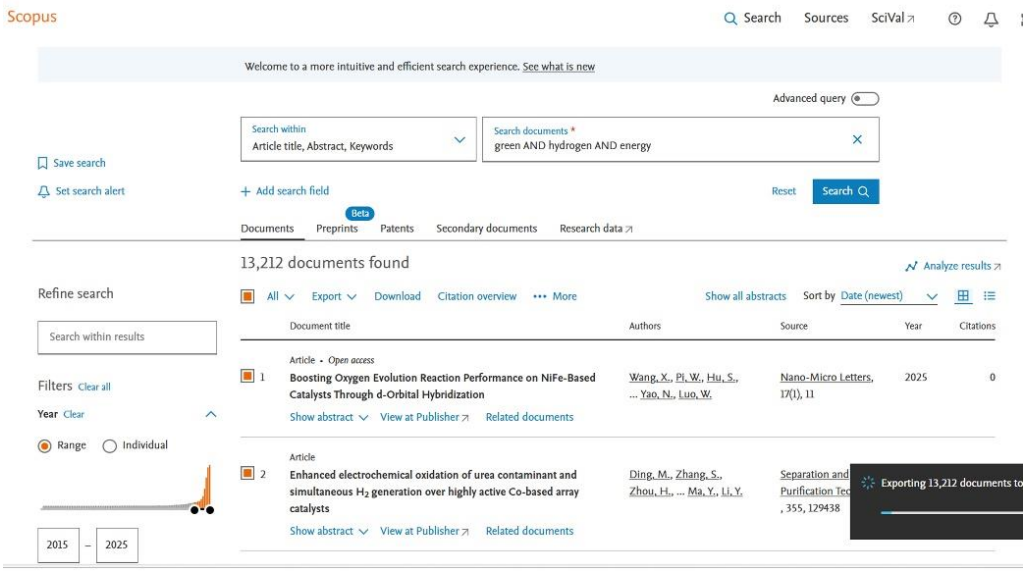

Figure 1 Scopus Search Results for Green Hydrogen Energy

13,212 documents were found in total when the first search was completed. This dataset served as the basis for the bibliometric study, allowing for a comprehensive investigation of authorship trends, publishing trends, and topic advancements in the subject of green hydrogen energy. Specialized criteria were used in the document selection process to guarantee the quality and relevance of the dataset. To capture the development and evolution of green hydrogen research in light of current international measures aiming at lowering carbon emissions and switching to sustainable energy sources, the study focused on papers released between 2015 and 2025. A variety of document categories, including reviews, conference papers, book chapters, and research articles, were included in the study. The study sought to provide a comprehensive picture of the state of the subject by including a range of publication formats and emphasizing both original research results and reviews that summarize prior findings. In order to reflect the multifaceted nature of green hydrogen research and its intersections with various fields like materials science, economics, and policy studies, the selected documents were drawn from a variety of subject areas, including engineering, environmental science, energy, and social sciences. To further guarantee the validity and dependability of the study results, only peer-reviewed publications were included, since the Scopus database is renowned for its exacting indexing of scholarly journals.

The final dataset was carefully chosen for analysis based on these selection criteria, guaranteeing that it included a thorough and relevant collection of research on green hydrogen energy. This study made use of VOSviewer, a potent software program for building, displaying, and analyzing bibliometric networks, to produce a number of visualizations that clarify the organization and dynamics of green hydrogen energy research. Using sophisticated algorithms to provide visual representations of complicated data, this program is extensively used in bibliometric investigations to show associations among authors, institutions, and keywords within a particular study subject. In this research, time series visualizations demonstrating the rise of publications pertaining to green hydrogen energy throughout the chosen time period were produced by publication trend analysis using VOSviewer. The present study yielded valuable insights on pivotal intervals of research activity. Specifically, it revealed peaks in publication volumes that align with noteworthy accomplishments in the area, including regulatory efforts or technical breakthroughs.

Furthermore, VOSviewer made it easier to map co-authorship networks, which made it possible to identify prominent writers and the collaborative links that support them. This study shed light on significant figures in green hydrogen research and the collaborative dynamics that define the area by displaying the relationships between the writers. In addition, the program made it possible to analyze keyword co-occurrences, which helped to determine which terms were used often in the chosen papers. Thematic clusters that represent the key areas of study and new developments in the field of green hydrogen energy were shown in this image. The study sought to identify areas of high interest and possible research gaps that call for more investigation by looking at the correlations among terms. Additionally, VOSviewer made it possible to visualize institutional cooperation, emphasizing the connections and contributions made by many research institutes to the field of green hydrogen research. This investigation shed light on international research networks and the contributions made by different institutions to the field's advancement of knowledge.

In order to get significant insights, the data that were extracted from Scopus and shown using VOSviewer underwent quantitative analysis. Important measures such as the number of publications, the frequency of citations, and the cooperation indices were computed to evaluate the contributions of certain authors, organizations, and nations to the field of green hydrogen energy research. An examination of the most frequently referenced papers and journals was also included into the study, which served as a basis for comprehending the important contributions made to the subject. By using a methodical approach, the study seeks to provide a thorough grasp of the state of the art in green hydrogen energy research, highlighting noteworthy figures, emerging themes, and possible directions for further investigation.

3 Results and discussions

The results of the bibliometric study of the area of green hydrogen energy research are presented in this section, with a focus on important trends, partnerships, and the geographic distribution of research activities.

A bibliographic network analysis of the leading writers and their partnerships in the area of green hydrogen energy research is shown in Figure 2. The thickness of the links shows the frequency of co-authorship, while the size of each node denotes the total number of publications. The graphic identifies the leading research groups and important field partners.

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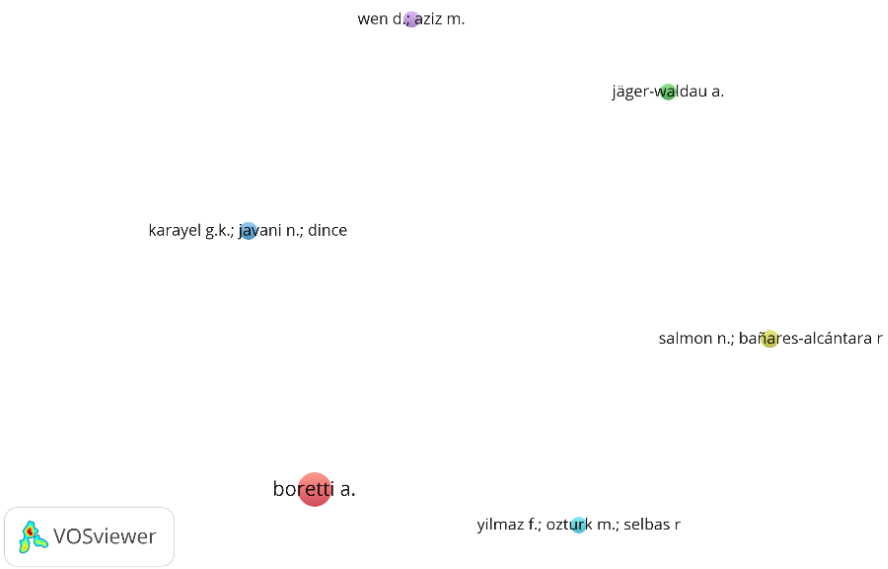

Figure 2 *Bibliometric Network Analysis of Green Hydrogen Energy Research for top authors*

A geographical representation of the research institutes engaged in green hydrogen energy research is shown in Figure 3. Each node's size corresponds to the amount of articles an organization has produced, and its color shows how research activity has changed over time. The map illustrates the geographic concentration of this field's research activities, with notable clusters located in North America, Europe, and Asia.

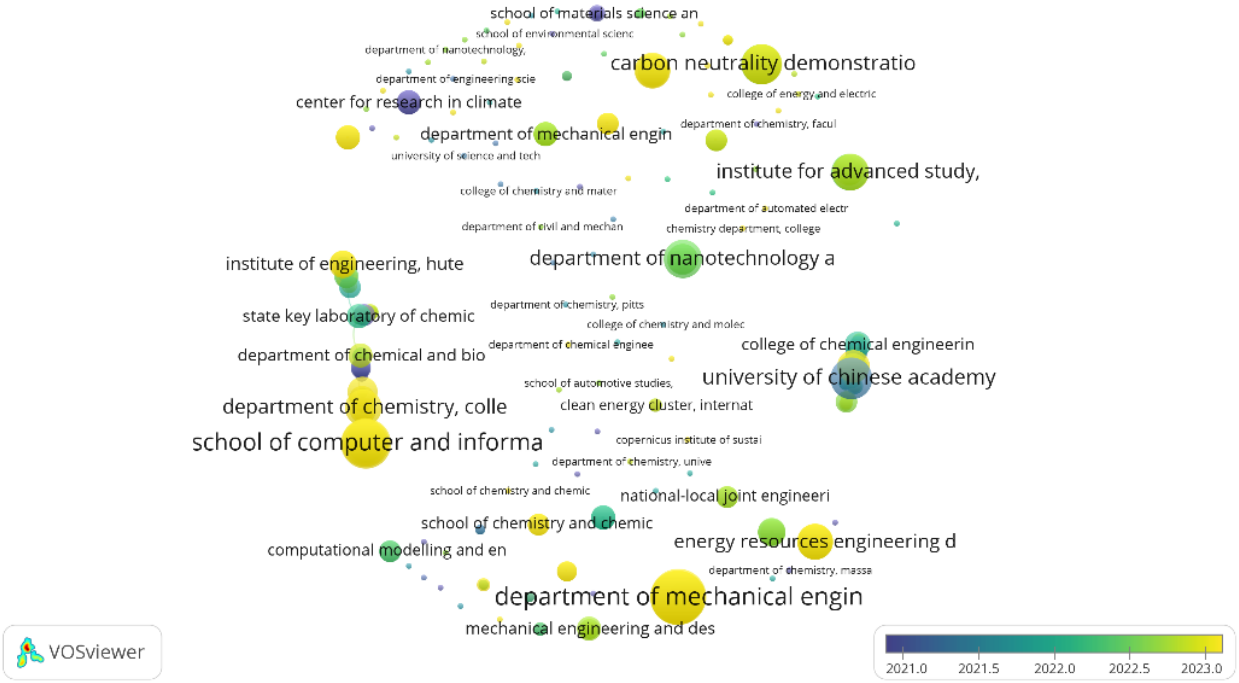

Figure 3 Geographic Distribution of Green Hydrogen Energy Research Institutions

The global network of co-authorship among nations doing research on green hydrogen energy is seen in Figure 4. The number of publications is represented by the size of each node, while the frequency of partnerships is shown by the thickness of the connections. The graphic displays the leading research alliances and cooperative collaborations among various geographical areas.

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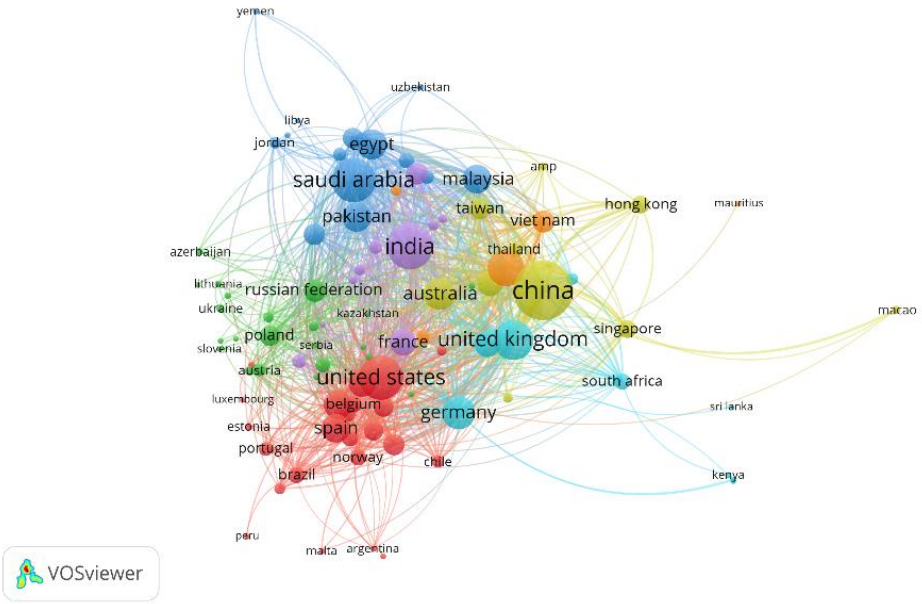

Figure 4 Geographic Collaboration Network in Green Hydrogen Energy Research

A keyword co-occurrence network based on phrases taken from the literature on green hydrogen energy is shown in Figure 5. Each node's size reflects how often a phrase occurs, while the links' thickness shows how strongly terms are associated. The graphic displays the main topics of the study as well as the connections between the most important ideas in the area.

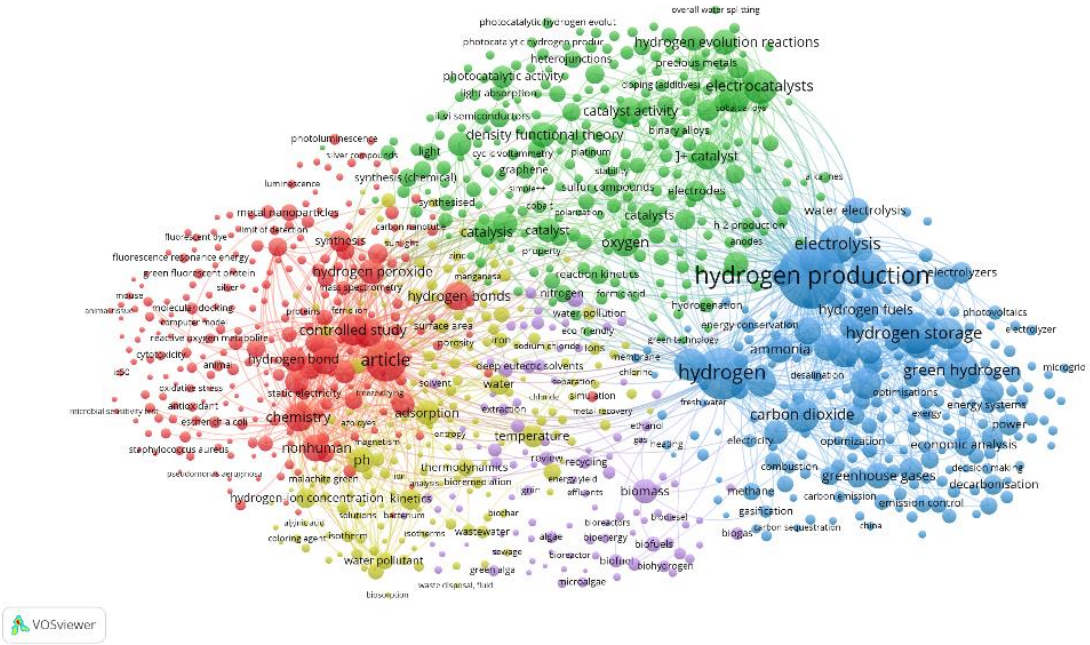

Figure 5 Keyword Co-occurrence Network for Green Hydrogen Energy Research

A keyword co-occurrence network with temporal analysis is shown in Figure 6, which highlights the development of research trends in green hydrogen energy. Each node's color and size correspond to the term's frequency and temporal distribution of use, respectively. The graphic illustrates how new fields of study are developing throughout time, while the importance of more established ones is waning.

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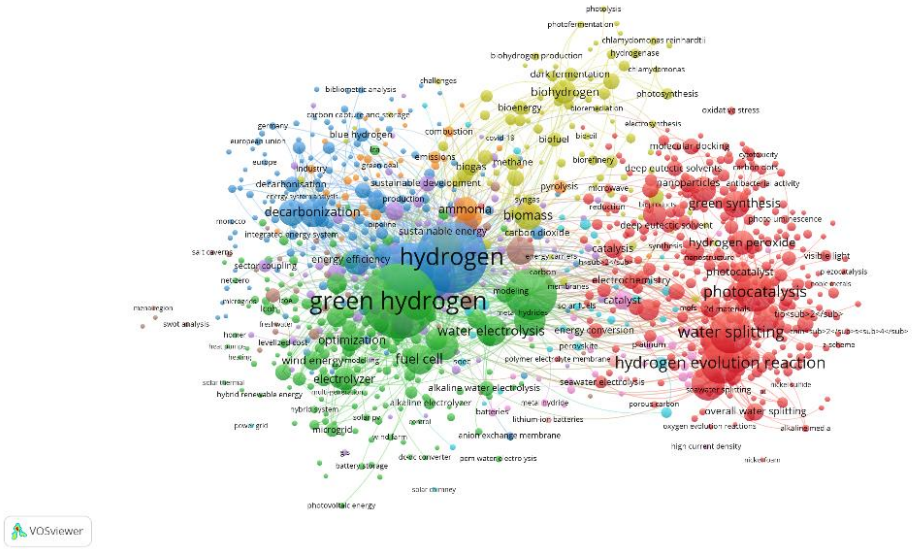

Figure 6 Keyword Co-occurrence Network with Temporal Analysis

With its depiction of a keyword co-occurrence network and temporal analysis, Figure 7 offers an alternate viewpoint on how research trends in green hydrogen energy have developed. Each node's color and size correspond to the term's frequency and temporal distribution of use, respectively. The graphic illustrates how new fields of study are developing throughout time, while the importance of more established ones is waning.

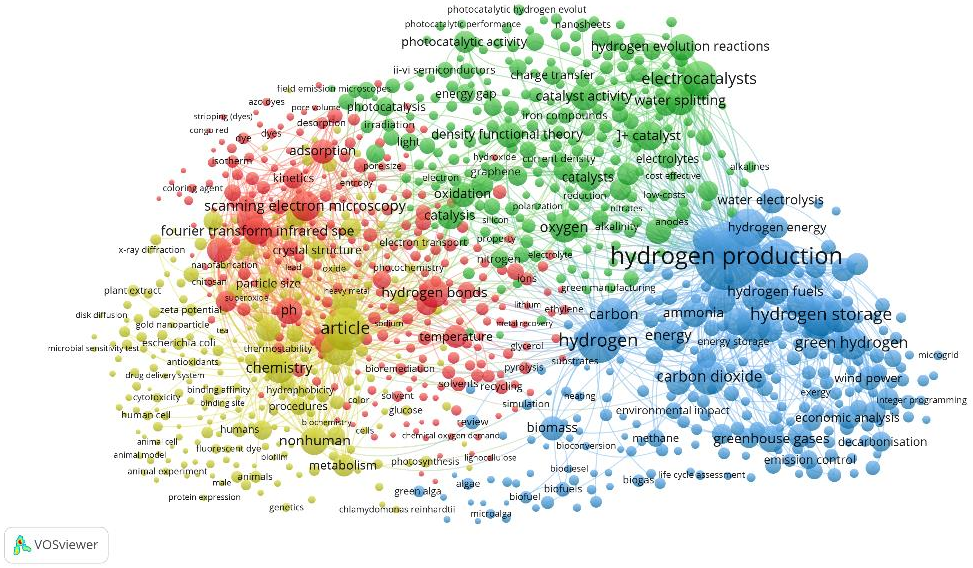

Figure 7 *Keyword Co-occurrence Network with Temporal Analysis (Alternative View)*

A bibliographic network analysis of the leading research organizations and cooperating authors in the area of green hydrogen energy is shown in Figure 8. The thickness of the links shows the frequency of co-authorship, while the size of each node denotes the total number of publications. The important collaborative relationships and dominating research clusters are shown in the graphic.

Figure 8 Bibliometric Network Analysis of Top Collaborators in Green Hydrogen Energy Research

A bibliographic network analysis of the leading journals that publish research on green hydrogen energy is shown in Figure 9. The thickness of the links shows the frequency of co-citation, while the size of each node reflects the total number of publications. The leading journals in the area are shown, along with their connections, in this image.

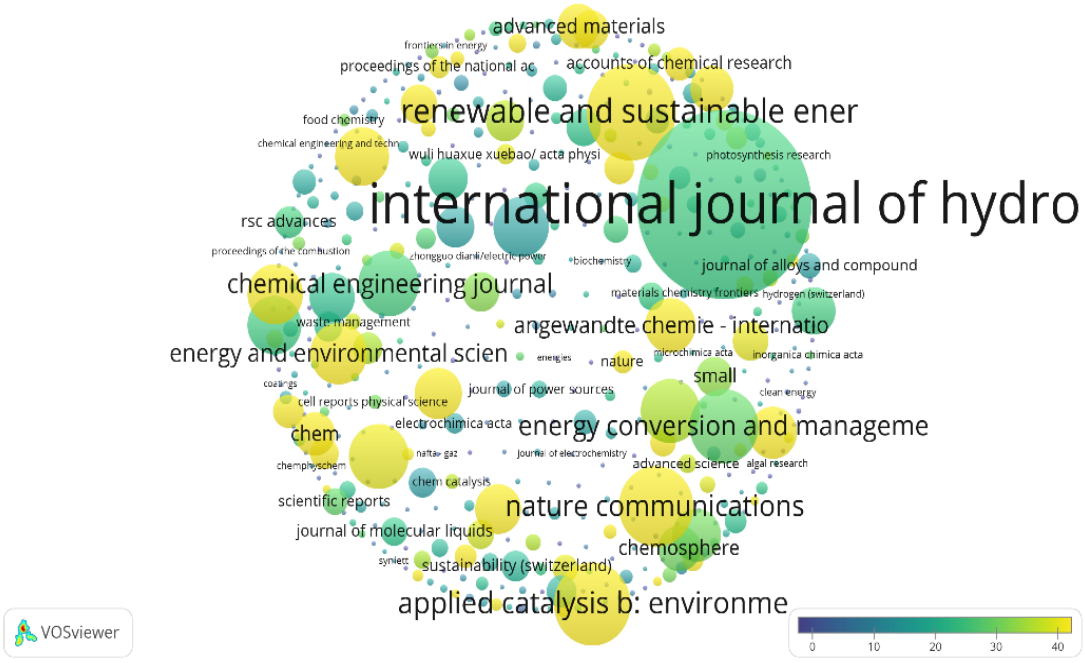

Figure 9 Bibliometric Network Analysis of Top Journals in Green Hydrogen Energy Research

A temporal study of a bibliographic network analysis of the leading research organizations and cooperating authors in the area of green hydrogen energy is shown in Figure 10. The thickness of the links shows the frequency of co-authorship, while the size of each node denotes the total number of publications. The time distribution of research activity is shown by the color of the nodes. The graphic shows the important collaborative relationships, the dominating research clusters, and how cooperation patterns have changed over time.

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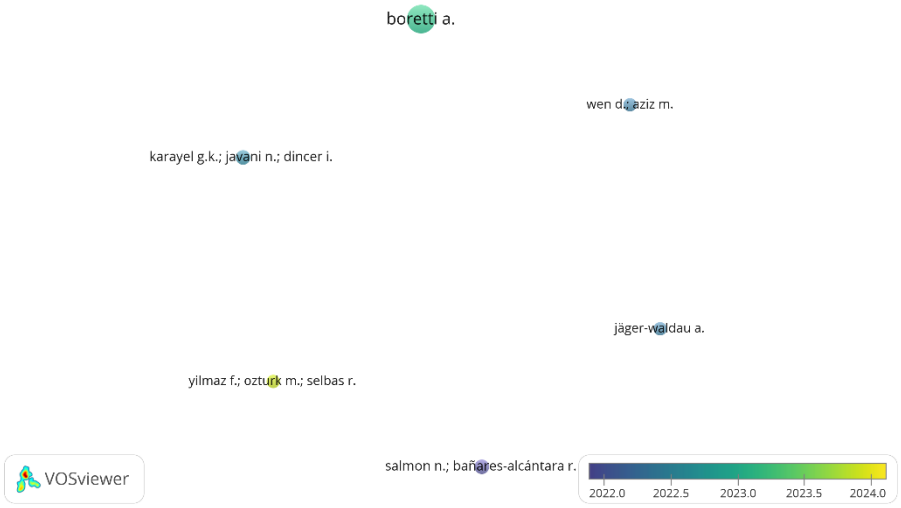

Figure 10 Bibliometric Network Analysis of Top Collaborators with Temporal Analysis

A geographical representation of the leading research institutes engaged in green hydrogen energy research is shown in Figure 11. Each node's size corresponds to the amount of articles an organization has produced, and its color shows how research activity has changed over time. The map illustrates the geographic concentration of this field's research activities, with notable clusters located in North America, Europe, and Asia.

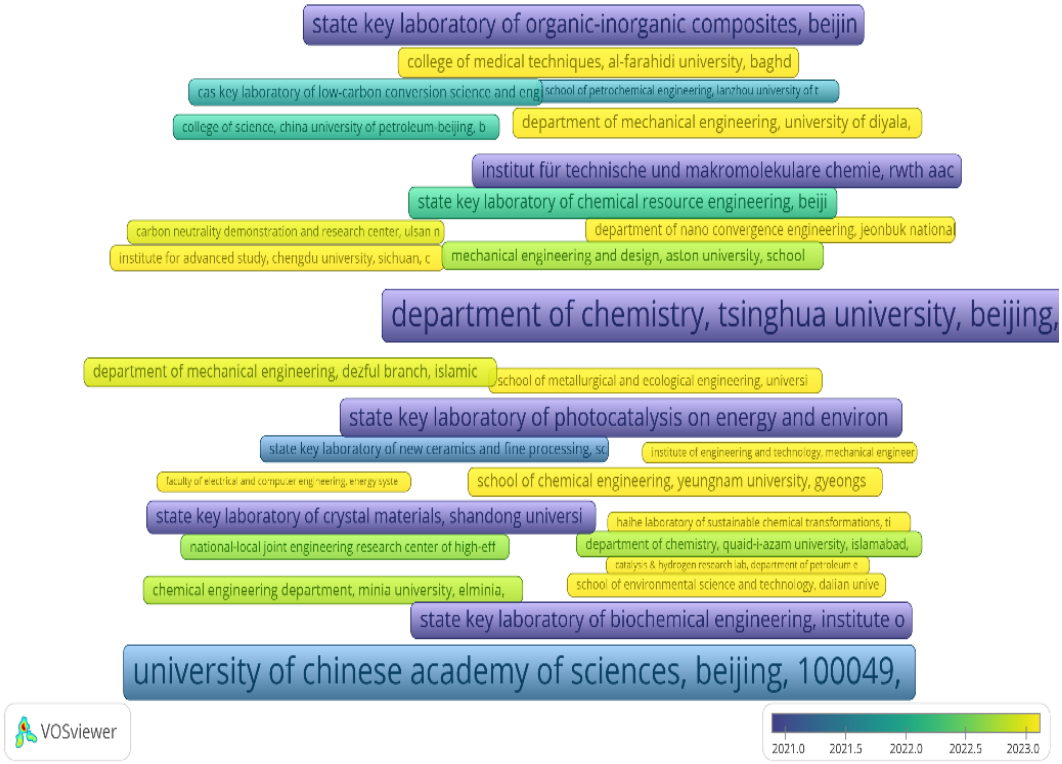

Figure 11 Geographic Distribution of Top Research Institutions in Green Hydrogen Energy

The global network of co-authorship among nations engaged in green hydrogen energy research is shown in Figure 12, offering an alternate viewpoint on the patterns of cooperation. The number of publications is represented by the size of each node, while the frequency of partnerships is shown by the thickness of the connections. The graphic displays the leading research alliances and cooperative collaborations among various geographical areas.

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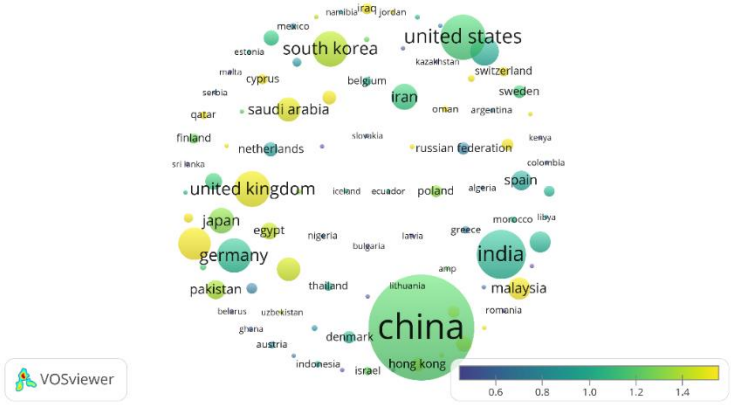

Figure 12 Geographic Collaboration Network in Green Hydrogen Energy Research (Alternative View)

Offering an alternate viewpoint on the development of cooperation patterns, Figure 13 shows a bibliographic network analysis of the leading research organizations and authors cooperating in the area of green hydrogen energy. The thickness of the links shows the frequency of co-authorship, while the size of each node denotes the total number of publications. The time distribution of research activity is shown by the color of the nodes. The graphic shows the important collaborative relationships, the dominating research clusters, and how cooperation patterns have changed over time.

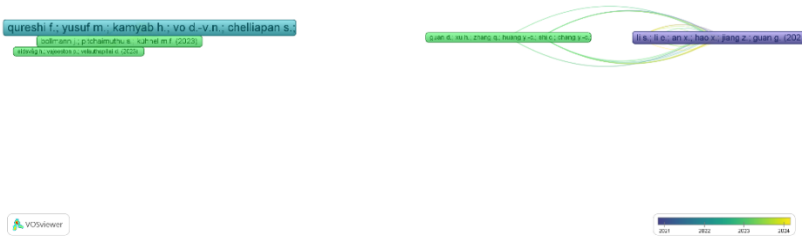

Figure 13 Bibliometric Network Analysis of Top Collaborators with Temporal Analysis (Alternative View)

A bibliographic network analysis with temporal analysis of the top journals publishing research on green hydrogen energy is shown in Figure 14. The thickness of the links shows the frequency of co-citation, while the size of each node reflects the total number of publications. The time distribution of research activity is shown by the color of the nodes. The graphic emphasizes the leading journals, their connections within the discipline, and how journal impact has changed over time.

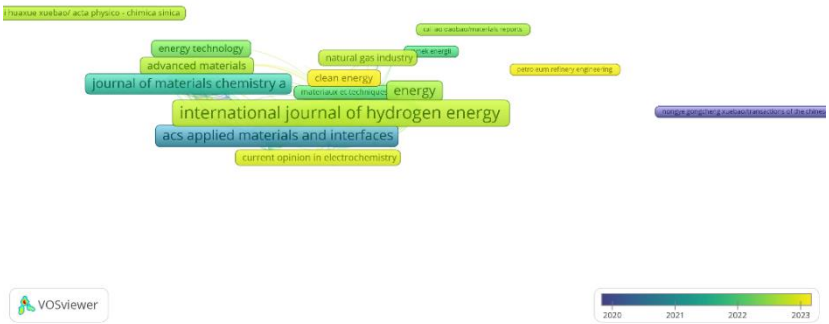

Figure 14 Bibliometric Network Analysis of Top Journals with Temporal Analysis

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Offering an alternate viewpoint on the development of cooperation patterns, Figure 15 shows a bibliographic network analysis of the leading research organizations and authors cooperating in the area of green hydrogen energy. The thickness of the links shows the frequency of co-authorship, while the size of each node denotes the total number of publications. The time distribution of research activity is shown by the color of the nodes. The graphic shows the important collaborative relationships, the dominating research clusters, and how cooperation patterns have changed over time.

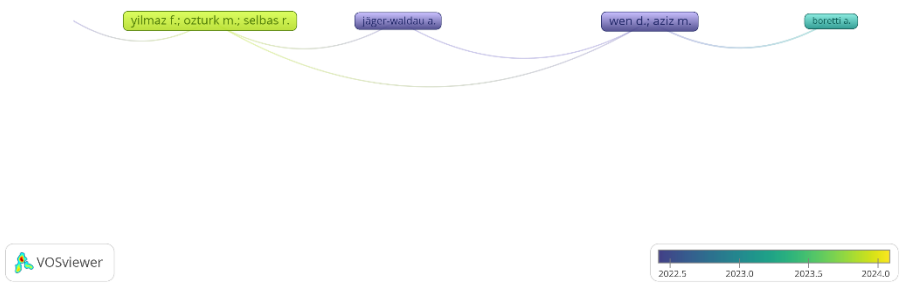

Figure 15 Bibliometric Network Analysis of Top Collaborators with Temporal Analysis (Alternative View)

A temporal study of a bibliographic network analysis of the leading research institutes engaged in green hydrogen energy studies is shown in Figure 16. The thickness of the links shows the frequency of co-authorship, while the size of each node denotes the total number of publications. The time distribution of research activity is shown by the color of the nodes. The graphic emphasizes the leading institutions, their connections within the discipline, and how institutional power has changed over time.

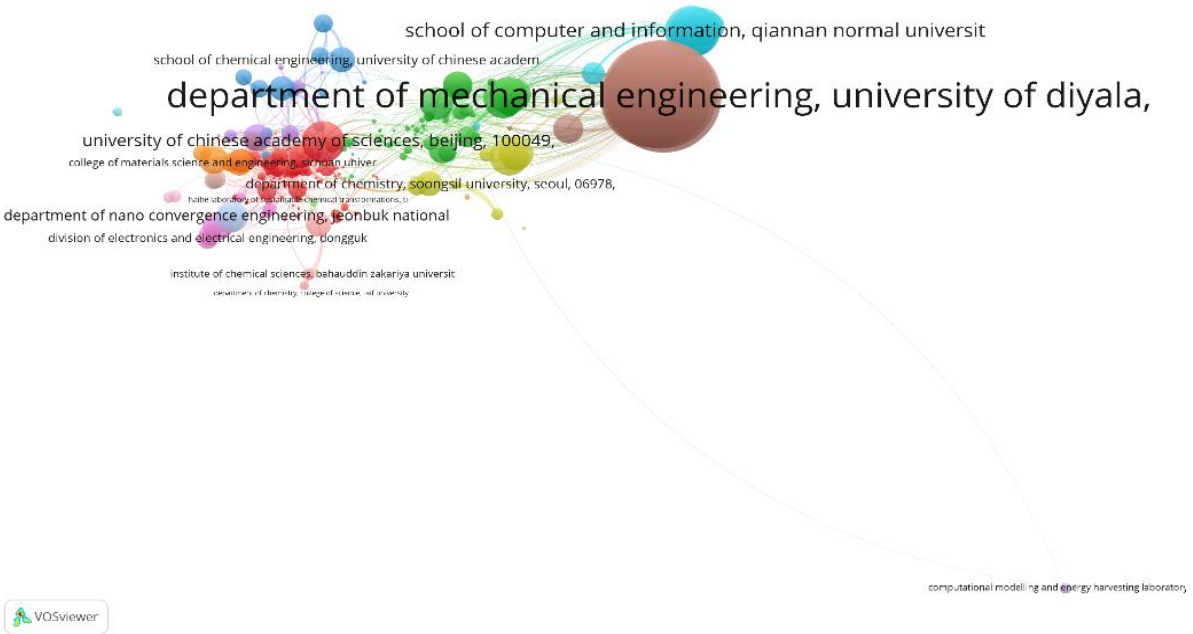

Figure 16 Bibliometric Network Analysis of Top Research Institutions with Temporal Analysis

The global network of co-authorship among nations engaged in green hydrogen energy research is shown in Figure 17, offering an alternate viewpoint on the patterns of cooperation. The number of publications is represented by the size of each node, while the frequency of partnerships is shown by the thickness of the connections. The graphic displays the leading research alliances and cooperative collaborations among various geographical areas.

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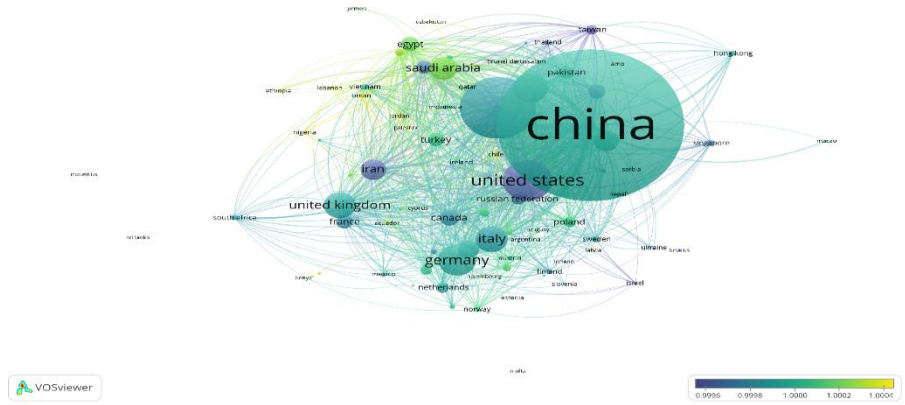

Figure 17 Geographic Collaboration Network in Green Hydrogen Energy Research (Alternative View)

A bibliographic network analysis of the most cited references in the area of green hydrogen energy is shown in Figure 18. The thickness of the links shows the frequency of co-citation, while the size of each node reflects the total number of citations. The most important studies are highlighted together with the connections between them in the literature.

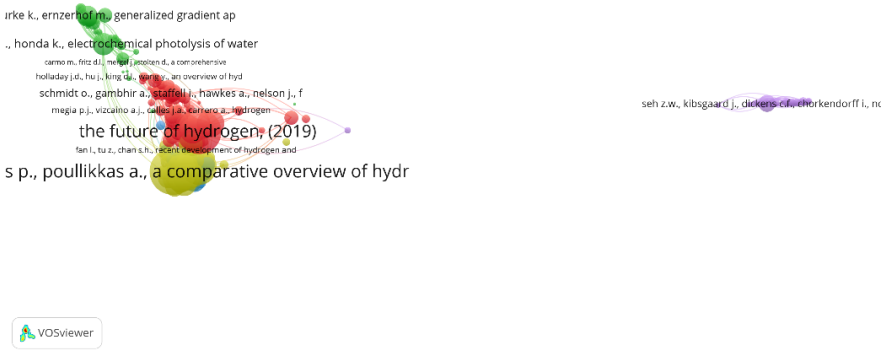

Figure 18 Bibliometric Network Analysis of Top Cited References in Green Hydrogen Energy Research

A temporal study of a bibliographic network analysis of the most cited references in the area of green hydrogen energy is shown in Figure 19. The thickness of the links shows the frequency of co-citation, while the size of each node reflects the total number of citations. The time distribution of citations is shown by the color of the nodes. The most important works are shown together with their connections in the literature and the changes in their citation patterns over time.

Figure 19 Bibliometric Network Analysis of Top Cited References with Temporal Analysis

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A bibliographic network analysis of the leading research organizations and cooperating authors in the area of green hydrogen energy is shown in Figure 20. The thickness of the links shows the frequency of co-authorship, while the size of each node denotes the total number of publications. The important collaborative relationships and dominating research clusters are shown in the graphic.

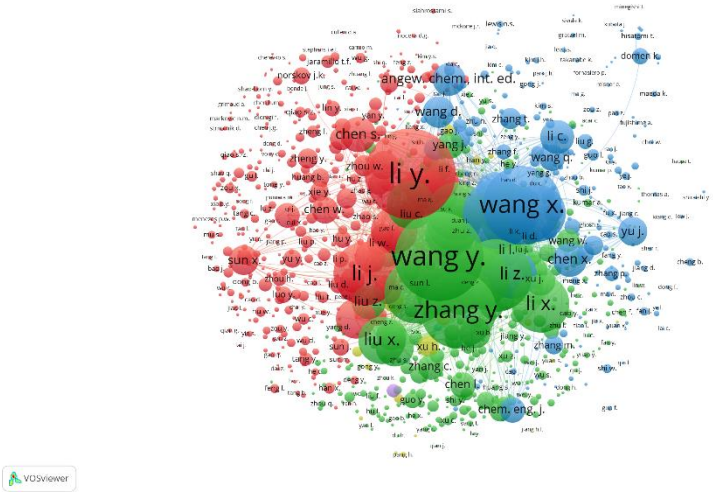

Figure 20 Bibliometric Network Analysis of Top Authors in Green Hydrogen Energy Research

The overall picture of green hydrogen energy research is one of vibrancy and change, according to the bibliometric study. The dynamic relationships within this subject are highlighted by the importance of important institutions and publications, worldwide partnerships, and significant research clusters. By providing a thorough overview, this thorough analysis paves the way for future research projects that will investigate and improve cooperative efforts in green hydrogen research, eventually advancing sustainable energy solutions. The research community's collaborative character and the geographical dispersion of its activities provide important insights into the present and potential future paths of green hydrogen energy studies.

4 Conclusion

This study's bibliometric analysis offers a thorough summary of how the field of green hydrogen energy research is developing. The results demonstrate the growing momentum and interest in this topic, as seen by the notable increase in publications during the last ten years. The study highlights the major players in the subject, such as well-known writers, organizations, and nations, in addition to the prevailing research issues and new developments.

The research exposes a worldwide research network that is distinguished by cross-border partnerships and a concentration on certain fields of study, such the generation, storage, and use of hydrogen. The results also emphasize how crucial certain nations are in advancing research and determining the course of the discipline, especially China, the US, and Germany. Additionally, the study finds important journals and articles that have advanced the field of green hydrogen energy research significantly.

For anyone interested in understanding the present and future orientations of green hydrogen energy research, researchers, policymakers, and industry stakeholders may get significant insights from the bibliometric analysis provided in this paper. The results may drive governmental choices intended to support the development and use of green hydrogen technologies, as well as future research endeavors and researcher cooperation.

Even though this paper offers a thorough summary of the field's research on green hydrogen energy, there are a few topics that still need to be investigated in more detail. Among them are:

• Detailed assessment of certain research themes: A more in-depth look at particular research subjects within the area, such hydrogen production techniques, storage technologies, and applications, might provide insightful information about the most recent developments and difficulties.

• Implications for the economy and policy: Examining the economic effects of research on green hydrogen energy, including cost-benefit evaluations and suggested policies, may help with investment strategies and decision-making.

• Social and environmental impacts: In order to evaluate the overall sustainability and acceptability of green hydrogen energy, it is essential to examine the social and environmental aspects of its production and consumption.

• Cross-disciplinary cooperation: Promoting cooperation among scientists from many fields, including engineering, chemistry, materials science, and environmental science, may result in creative ideas and quicken the development of green hydrogen research.

• International partnerships: Encouraging worldwide collaboration and information exchange will help create best practices and international standards for green hydrogen energy, which will guarantee its wide-spread use and effects. Researchers may contribute to a more thorough knowledge of green hydrogen energy and its potential to be a key player in the shift to a sustainable energy future by tackling these topics in future studies.

5 Declarations

Competing Interests

The authors have disclosed no relevant conflicting interests that relate to the subject matter of this research paper.

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