# Bibliometric green and hidrogen

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**Abstract.** Green hydrogen, produced via electrolysis using renewable energy sources, is gaining prominence as a sustainable alternative to conventional fossil fuels, playing a vital role in the global transition towards a low-carbon economy. This study conducts a bibliometric analysis of green hydrogen research indexed in Scopus to map the evolution, trends, and key contributions in this field. By examining publication volume, citation impact, and collaboration networks, the analysis identifies leading countries, institutions, authors, and journals that are driving innovation in green hydrogen technologies. The findings highlight the rapid growth in green hydrogen research, fueled by increasing global efforts to combat climate change and reduce greenhouse gas emissions. Major research themes include advancements in electrolysis technologies, hydrogen storage and transportation, and applications across industrial, energy, and transportation sectors. Despite the progress, challenges such as high production costs, storage inefficiencies, and policy barriers remain prominent. This bibliometric review not only provides a comprehensive overview of the current research landscape but also identifies critical gaps and future research directions essential for advancing green hydrogen technologies. The results underscore the importance of interdisciplinary collaboration and strategic policy support in accelerating the adoption of green hydrogen as a cornerstone of the sustainable energy future.

## 1 Introduction

Green hydrogen, produced through electrolysis using renewable energy sources, has gained significant attention as a sustainable alternative to fossil fuels [1], contributing to decarbonization efforts globally As the urgency to address climate change intensifies, research and development in green hydrogen technology have accelerated, focusing on improving efficiency, reducing costs, and enhancing the scalability of production and storage methods [2,3].

Bibliometric analysis offers a comprehensive approach to assess the progression of green hydrogen research by evaluating the volume, impact, and collaborative networks of scientific publications over time This method provides insights into the key research trends, influential authors, and significant journals contributing to the field. Additionally, bibliometric analysis helps in identifying research gaps, emerging technologies, and policy implications, guiding future research directions and strategic investments

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By systematically analyzing the existing literature, this study aims to map the evolution of green hydrogen research, highlighting the dominant themes and potential areas for innovation. The findings of this bibliometric study will contribute to a better understanding of the current landscape and future prospects of green hydrogen technologies, facilitating informed decision-making for researchers, industry stakeholders, and policymakers [4].

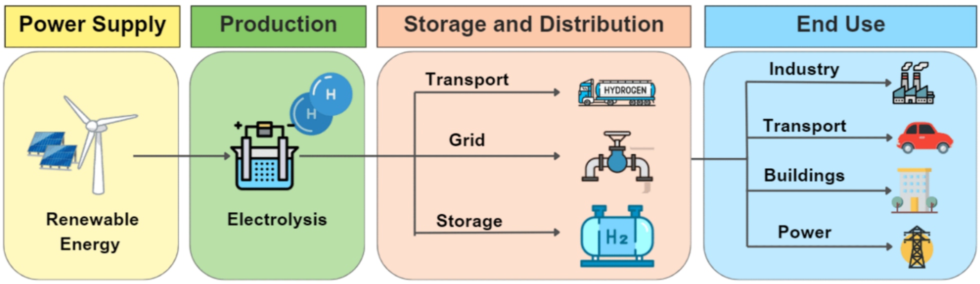


**Fig. 1** green hydrogen with renewable energy [5]

### 1.1 Relationship Between Green Energy and Hydrogen

Green hydrogen represents a crucial intersection between renewable energy sources and hydrogen production, offering a sustainable pathway for reducing greenhouse gas emissions [6]. Hydrogen, as an energy carrier, can be produced through various methods, but green hydrogen specifically refers to hydrogen generated by splitting water molecules using electricity derived from renewable sources such as wind, solar, and hydropower This method of production is carbon-free, unlike traditional hydrogen production methods that rely on fossil fuels and emit significant amounts of $CO_2$, such as steam methane reforming The role of green hydrogen in the broader green energy ecosystem is vital due to its versatility and potential to decarbonize various sectors, including transportation, industry, and energy storage ). In the energy sector, green hydrogen can be stored and used to produce electricity during periods of high demand or low renewable energy generation, effectively complementing intermittent renewable sources In the transportation sector, it serves as a clean fuel for fuel cell electric vehicles (FCEVs), which emit only water vapor, thereby reducing air pollution and dependency on fossil fuels [7–9].

Furthermore, green hydrogen facilitates the integration of renewable energy into the grid by providing a means of storing excess electricity generated during peak production times. This capability addresses one of the main challenges of renewable energy sources—variability and intermittency The synergy between green energy and hydrogen thus not only promotes energy security but also contributes to achieving global climate targets by reducing carbon footprints across multiple sectors [10,11].

## 2 Literature Review

### 2.1 Literature Review on Green Hydrogen

From this research title The Green Hydrogen Energy Systems: A Review on Their Contribution to a Renewable Energy System

Accelerating the transition to a cleaner global energy system is essential for combating the climate crisis, and green hydrogen offers significant potential for integrating renewable energy. This paper evaluates green hydrogen's role in achieving near-zero greenhouse gas

(GHG) emissions, exploring current technologies, industry status, and future challenges. An economic analysis assesses the feasibility of green hydrogen, with the levelized cost of hydrogen (LCOH) ranging from EUR 1.12/kg to EUR 16.06/kg, depending on geography and technology. Green hydrogen shows promise in reducing GHG emissions, especially in hard-to-decarbonize sectors, with a target LCOH of EUR 1/kg by 2050 achievable in some regions. However, challenges remain, including the need for technological advancements and policies to lower costs in electrolyzer production, which is crucial for green hydrogen's viability [5].

### 2.2 Introduction to Green Hydrogen

Green hydrogen is increasingly recognized as a critical component in the transition towards a low-carbon economy. Unlike conventional hydrogen production methods, such as steam methane reforming (SMR), which emit substantial $CO_2$, green hydrogen is produced via electrolysis powered by renewable energy sources like solar, wind, and hydropower, making it a carbon-neutral option. The development of green hydrogen is driven by the urgent need to mitigate climate change and reduce dependency on fossil fuels, positioning it as a pivotal technology for achieving global decarbonization targets [12,13].

### 2.3 Technological Developments and Challenges

Electrolysis, the primary technology for green hydrogen production, has seen significant advancements in efficiency and cost reduction, particularly with proton exchange membrane (PEM) and alkaline electrolysis technologies [14]. However, challenges remain, including the high capital costs of electrolyzers, the need for abundant and low-cost renewable electricity, and the current inefficiencies in hydrogen storage and transport Innovations such as solid oxide electrolyzers and advancements in catalyst materials are being explored to enhance efficiency and reduce costs [15].

### 2.4 Applications of Green Hydrogen

Green hydrogen’s versatility makes it suitable for various applications, including:

- Energy Storage: Green hydrogen acts as a medium for storing excess electricity from renewable sources, helping to balance supply and demand and providing a solution to the intermittency of renewables [16].
- Industrial Use: It can decarbonize hard-to-abate industries such as steel, chemicals, and refining, where electrification alone is insufficient [17,18].
- Transportation: Hydrogen fuel cells offer a zero-emission alternative for heavy-duty vehicles, buses, and trains, where battery electric solutions may be less practical due to weight and range considerations [19].

### 2.5 Economic and Policy Considerations

The economic viability of green hydrogen hinges on reducing production costs, which are currently higher than those of grey or blue hydrogen (hydrogen produced from fossil fuels with carbon capture and storage). Government policies, including subsidies, carbon pricing, and investments in hydrogen infrastructure, play a crucial role in accelerating the adoption of green hydrogen technologies [20,21].

Global interest is also growing, with several countries announcing national hydrogen strategies aimed at scaling up production, fostering international trade, and setting regulatory frameworks to support the hydrogen economy [22,23].

### 2.6 Environmental and Sustainability Impacts

Green hydrogen has the potential to significantly reduce greenhouse gas emissions across various sectors, contributing to climate goals such as the Paris Agreement .Its environmental footprint is minimal compared to conventional hydrogen, provided that the renewable electricity used is sourced sustainably .However, the scalability of green hydrogen production must be managed carefully to avoid unintended impacts, such as land use conflicts and resource depletion associated with large-scale renewable energy installations [24–26].

### 2.7 Future Prospects and Research Directions

The future of green hydrogen looks promising with ongoing research focused on improving electrolysis efficiency, developing new storage solutions, and integrating hydrogen into existing energy systems Additionally, breakthroughs in hydrogen distribution, such as blending with natural gas or using existing pipeline infrastructure, could reduce the costs associated with hydrogen transport [27].

The literature suggests that interdisciplinary collaboration among researchers, industry stakeholders, and policymakers is essential to overcoming the current barriers to green hydrogen adoption and realizing its full potential as a cornerstone of the future energy landscape [28–30].

## 3 Material and Methods

This study employs a bibliometric analysis to explore the scientific landscape of green hydrogen research published in 2023, using data retrieved from Scopus and analyzed with the R package Bibliometrix. Data collection involved querying Scopus with keywords related to green hydrogen, focusing on publications from 2023 and including articles, reviews, and conference papers in English. The data was exported in BibTeX format and imported into R for analysis. Descriptive metrics, such as the number of publications, sources, and most prolific authors, were calculated using Bibliometrix functions. Network analyses, including co-authorship, co-citation, and keyword co-occurrence, were conducted using the biblioshiny() interface to visualize collaboration patterns among researchers, institutions, and countries. Thematic mapping techniques identified key research themes and their evolution over time. The results were visualized through various plots, such as collaboration maps and thematic maps, providing insights into trends, research hotspots, and gaps in the literature. To ensure reliability, data was cross-checked for duplicates and reviewed for accuracy, providing a comprehensive understanding of the current state and future directions of green hydrogen research.

## 4 Results and Discussion

Fig. 2 displays a blue and white menu with various metrics related to a research project or publication. The project covers the year 2023 and includes 3963 documents from 947 sources, authored by 13,453 individuals. The annual growth rate is 0%, and there are an average of 5.99 co-authors per document, with 27.88% of the authors being international.

The project uses 10,573 keywords related to authors and has an average document age of 1 year, with an average of 8,687 citations per document.

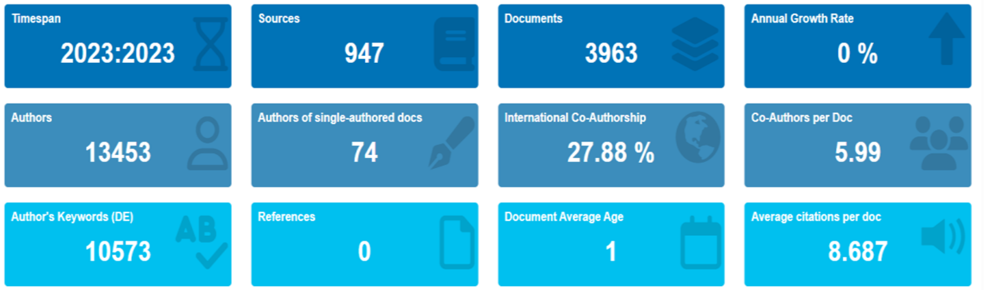


**Fig. 2.** Main Menu

Fig 3 is a bar chart titled "Most Relevant Authors" showing the number of documents authored by each author. The authors are listed on the left-hand side of the chart, and the number of documents they have authored is shown on the right-hand side. The chart shows that the author "WANG Y" has authored the most documents, with 133 documents. The author "LI Y" has authored the second most documents, with 105 documents. The remaining authors have authored between 77 and 102 documents. The chart is a useful tool for identifying the most prolific authors in a given field of study.

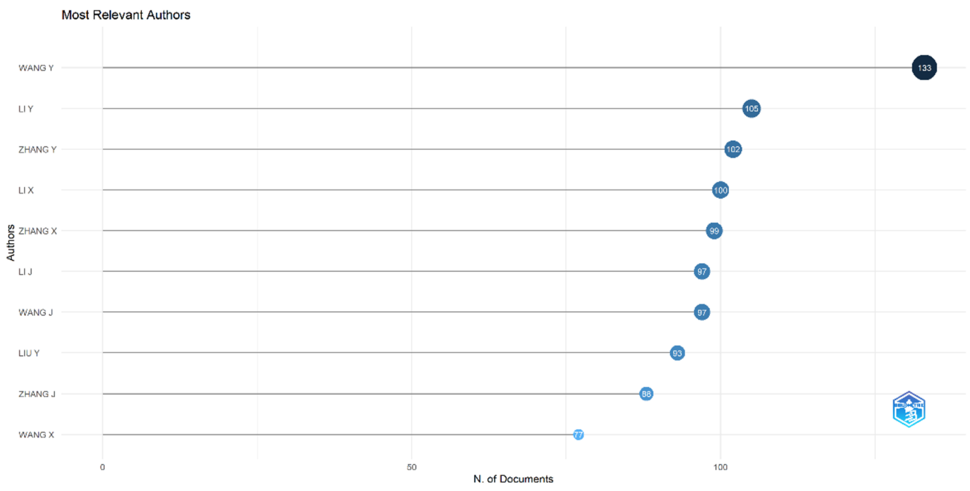


**Fig. 3.** Most relevant authos

The bar chart as show in Fig. 4, titled "Most Relevant Sources," visually represents the number of documents contributed by various sources. The source "International Journal of Hydrogen Energy" stands out as the most prolific contributor, having provided 205 documents. Following closely is "Chemical Engineering Journal" with 107 documents. The remaining sources, including "International Journal of Biological Macromolecules," "ACS Sustainable Chemistry and Engineering," "Fuel," "Energies," "Environmental Science and Pollution Research," "Journal of Cleaner Production," "Energy Conversion and Management," and "Chemosphere," have contributed a range of documents, from 49 to 89. This chart offers a clear visual representation of the sources that have significantly contributed to the research project or publication, highlighting their importance within the field of study.

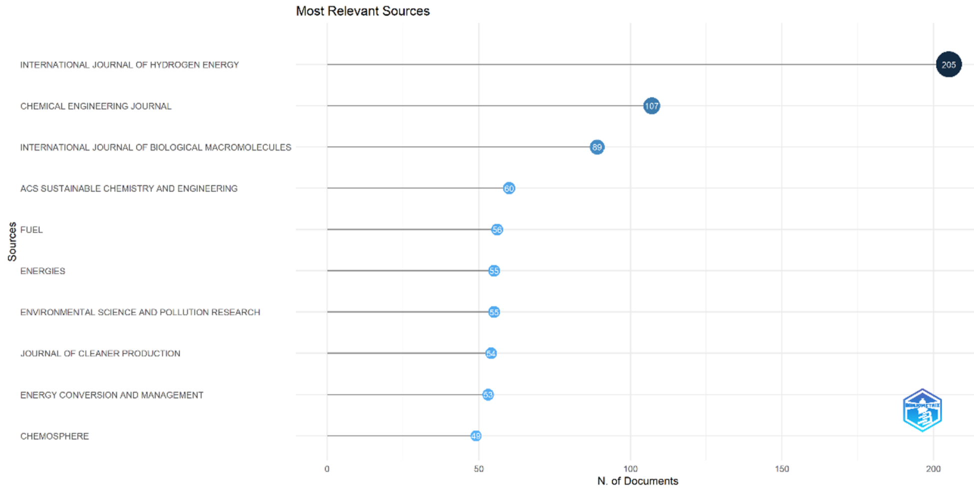


**Fig. 4.** Most relevant sources

Fig. 5 is a bar chart titled "Most Cited Countries" showing the number of citations for each country. The countries are listed on the left-hand side of the chart, and the number of citations is shown on the right-hand side. The chart shows that China has the most citations, with 5502 citations. Germany has the second most citations, with 2370 citations. The remaining countries have between 39 and 2086 citations. The chart is a useful tool for identifying the most cited countries in a given field of study.

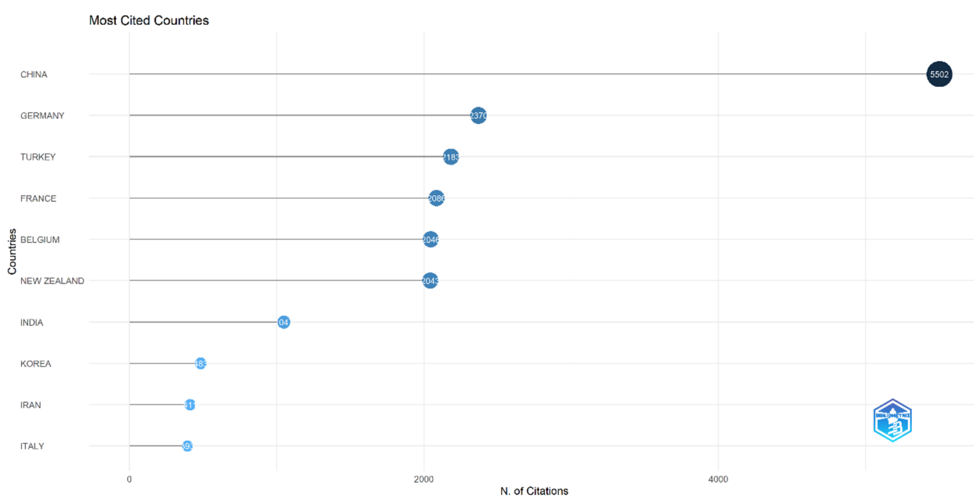


**Fig. 5** Most cited countries

Fig 6 is a treemap that visually represents the distribution of research topics related to hydrogen production. The size of each rectangle corresponds to the number of documents related to that topic.

The largest rectangle, representing "hydrogen production," accounts for 7% of the research. Other prominent topics include "adsorption" (4%), "hydrogen bonds" (4%), "article" (6%), and "hydrogen" (4%).

The treemap also reveals other important research areas, such as "electrocatalysts," "electrolysis," "chemistry," "water," "oxygen," "carbon," "ph," "hydrogen storage," "catalysts," "synthesis," "temperature," "metabolism," "solvents," "solar energy," "catalyst," "water electrolysis," and "particle size."

The treemap provides a clear overview of the research landscape related to hydrogen production, highlighting the most prevalent topics and their relative importance within the field.


**Fig. 6.** Tree Map

The Fig. 7. is a thematic map that plots research themes based on their relevance and development degree. The horizontal axis represents the relevance degree, also known as centrality, with "Emerging or Declining Themes" on the left and "Basic Themes" on the right. The vertical axis represents the development degree, also known as density, with "Niche Themes" at the top and "Motor Themes" at the bottom.

The map currently shows one theme, "article hydrogen bonds controlled study," positioned in the top left quadrant, indicating it is a niche theme with a high development degree but low relevance.

This thematic map is a useful tool for visualizing the evolution of research themes, allowing researchers to identify emerging areas of interest and understand the relative importance of different research topics

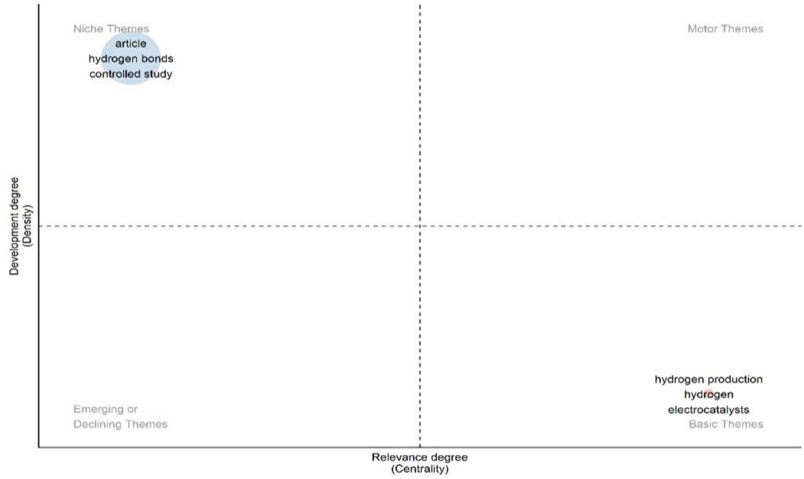


**Fig 7** Thematip map

The Fig. 8 shows a collaborative network of researchers in green hydrogen, represented by a network graph where nodes indicate individual researchers and edges represent their collaborative relationships. The nodes are color-coded into three main clusters: red, green, and blue, each reflecting distinct research communities. The red cluster, featuring prominent researchers like Wang J and Zhang X, displays dense interconnections, indicating strong internal collaboration. The green cluster, centered around Wang Y, Liu Y, and Li Y, also shows a robust network of connections, while the blue cluster, with researchers such as Zhang Y and Li Z, appears more dispersed and less interconnected. Larger nodes like Wang Y and Wang J represent key figures with high connectivity within their groups. The network includes numerous inter-cluster connections, shown by gray edges, highlighting interdisciplinary collaborations across the field. This interconnectedness suggests a well-integrated research landscape, with both distinct communities and broader cross-group collaborations driving advancements in green hydrogen research.

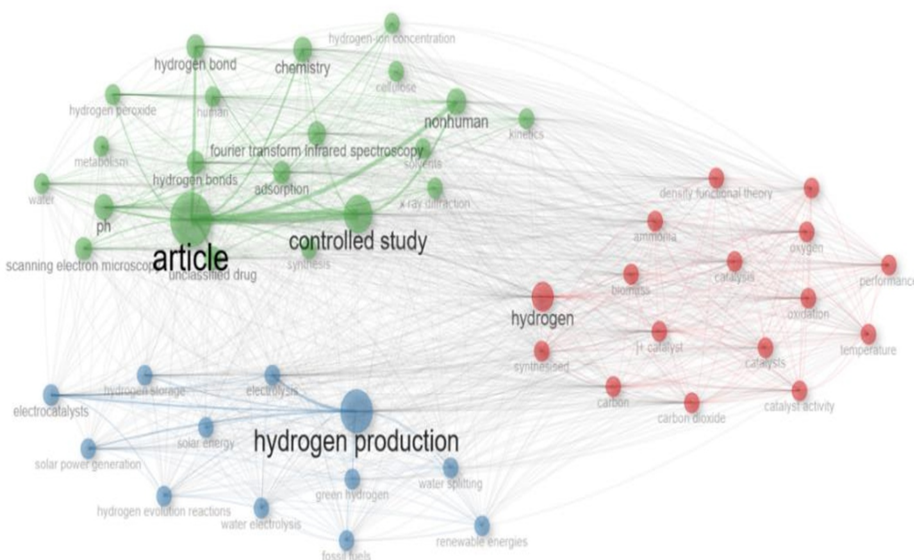


Fig. 8. Collaboration network researchers green hydrogen

The map illustrates as show in Fig. 9 the global distribution of scientific production related to green hydrogen, with countries shaded in varying shades of blue to indicate their level of output. Darker blue shades represent higher levels of scientific production, with China standing out as the most significant contributor, shown in the darkest blue. Other countries with notable contributions, though to a lesser extent than China, include the United States, several European nations such as Germany and the United Kingdom, and countries in East Asia, such as Japan and South Korea. Light blue shading indicates countries with moderate to low levels of scientific output in this field, while grey areas represent regions with minimal or no recorded contributions. The overall distribution emphasizes the prominent role of China in driving green hydrogen research, along with significant activity from other technologically advanced and research-focused countries globally.

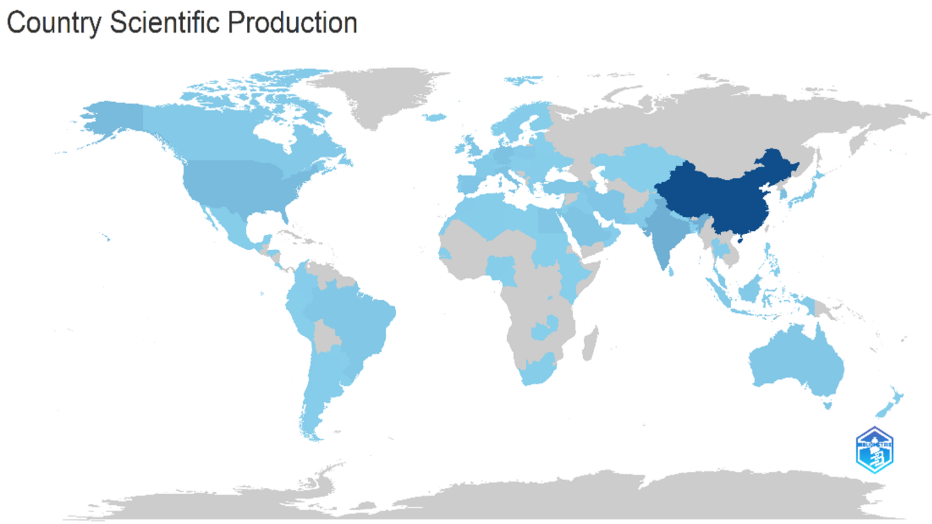


Fig. 9. Country scientific production

The map illustrates international collaboration networks in green hydrogen research as show in Fig. 10, highlighting various countries with blue shading, where darker shades indicate higher levels of activity or significance, particularly China, which stands out as a major hub of collaboration. Red lines represent research links, showing dense connections in Europe, Asia, and North America, reflecting strong international partnerships. China is a central player with extensive links to many countries, especially in Asia, Europe, and North America. Europe also displays a high density of collaborations, particularly among countries like Germany, the UK, and France, indicating a robust regional research network. The United States and other countries in North America are also significant nodes in this global network. The widespread lines demonstrate the interconnectedness of green hydrogen research worldwide, underscoring the critical role of international collaboration in advancing the field.

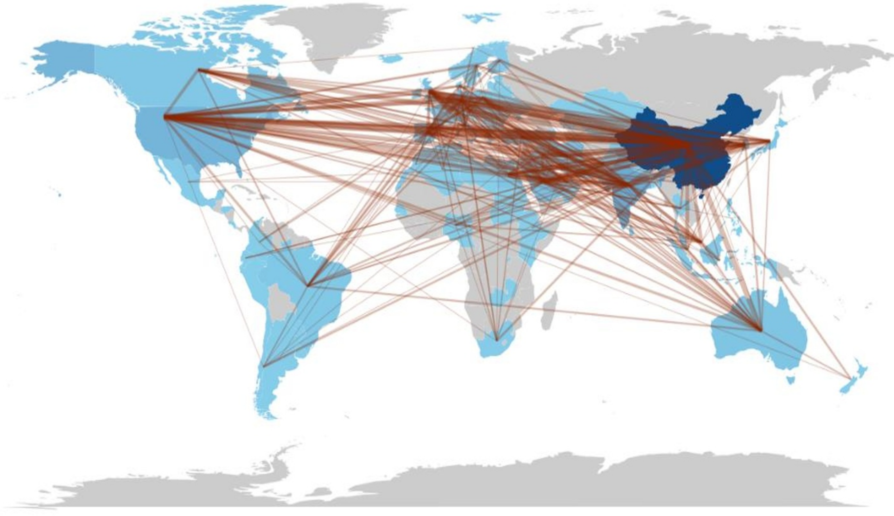

**Fig. 10**. International collaboration networks

## 5 Conclusion

This research about bibliometric green hydrogen with index scopus with key word green and hydrogen , The project covers the year 2023 and includes 3963 documents from 947 sources, authored by 13,453 individuals. The annual growth rate is 0%, and there are an average of 5.99 co-authors per document, with 27.88% of the authors being international. The project uses 10,573 keywords related to authors and has an average document age of 1 year, with an average of 8,687 citations per document. Most relevant authors the author "WANG Y" has authored the most documents, with 133 documents. The author "LI Y" has authored the second most documents, with 105 documents. The remaining authors have authored between 77 and 102 documents. International collaboration China is a central player with extensive links to many countries, especially in Asia, Europe, and North America. Europe also displays a high density of collaborations, particularly among countries like Germany, the UK, and France, indicating a robust regional research network, in tree map The largest rectangle, representing "hydrogen production," accounts for 7% of the research. Other prominent topics include "adsorption" (4%), "hydrogen bonds" (4%), "article" (6%), and "hydrogen" (4%)The treemap also reveals other important research areas, such as "electrocatalysts," "electrolysis," "chemistry," "water," "oxygen," "carbon," "ph," "hydrogen storage," "catalysts," "synthesis," "temperature," "metabolism," "solvents," "solar energy," "catalyst," "water electrolysis," and "particle size.

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