Volume: 9 Issue: 1 Month: 1, Year: 2026
P.P 442 - 475
مجلة البحوث القانونية والاقتصادية
JOURNAL OF LEGAL AND ECONOMIC RESEARCH

HYDROGEN ECONOMY (2015–2026): MAPPING GLOBAL RESEARCH TRENDS THROUGH BIBLIOMETRIC ANALYSIS

AIT BACHIR Lynda*
University Center -Aflou- El Cherif Bouchoucha-(Algeria)
l.ait_bachir@cu-aflou.edu.dz
Laboratory for Legal and Economic Research

Send Article Date: 25-10-2025	Date of acceptance of the article: 16-12-2025

Abstract:
This study presents a comprehensive bibliometric mapping of global research on the hydrogen economy from 2015 to 2026, based on 3,747 Scopus-indexed publications. Using Python, R-Studio (Bibliometrix), and VOSviewer, the analysis explores performance metrics, thematic evolution, and structural relationships. Findings reveal a sharp post-2020 surge in publication volume, aligned with international decarbonization policies. The field exhibits a bipolar conceptual structure, bridging strategic-economic themes (e.g., energy transition) with fundamental scientific research (e.g., electrocatalysis, water splitting). Co-citation analysis identifies four intellectual pillars: policy frameworks, sustainable production, storage technologies, and integrative reviews. China leads in output and network centrality, while the U.S. and U.K. function as global connectors. Notably, 31.8% of publications resulted from international collaboration, underscoring the global scope and interdisciplinary nature of the field. This study offers a domain-wide synthesis that extends beyond prior reviews, providing strategic insights for researchers, policymakers, and energy innovators.
key words: Hydrogen economy; Bibliometric analysis; Science mapping; VOSviewer; Energy transition.
JEL Classification: Q42, O32, Q48

1. Introduction

Hydrogen is increasingly recognised as a transformative energy carrier capable of bridging multiple sectors—industry, transportation, power generation, and energy storage—within the

* AIT BACHIR Lynda.

global decarbonisation agenda. Its appeal arises from its versatility and, when produced via low-carbon pathways, its potential to emit practically zero CO_2 at the point of use. According to the International Energy Agency, global hydrogen production reached approximately 97 Mt in 2023, yet less than 1 % came from low-emissions routes. (*Hydrogen Production – Global Hydrogen Review 2024 – Analysis*, 2024)

In tandem with falling renewable electricity costs and advances in electrolyser technologies, many national and regional governments have adopted hydrogen strategies and roadmaps that position hydrogen as a key pillar of their climate-neutral commitments. For example, systematic reviews highlight that renewable-based ("green") hydrogen can reduce greenhouse-gas emissions by 50–90 % compared to fossil-based hydrogen without carbon capture, though significant environmental trade-offs remain. (Terlouw et al., 2024)

Despite this rising interest and policy momentum, the hydrogen economy remains at an early stage of real-world deployment, constrained by high production costs, infrastructure gaps, storage challenges, and the complexity of integrating hydrogen systems across disciplines. Bibliometric mapping can play a pivotal role in navigating this complex field: by analysing patterns in publications, citations, keywords and collaborations, it reveals thematic evolution, intellectual structure and research gaps. Recent bibliometric studies in hydrogen have focused narrowly on specific subsystems, such as production or storage technologies eg: (Jeje et al., 2024) review of production methods.

This study addresses the gap in comprehensive domain-wide bibliometric assessments by analysing Scopus-indexed literature on the hydrogen economy from 2015 to 2026. Employing keyword co-occurrence, citation mapping, thematic clustering and collaboration network visualisation, the paper aims to:

- Identify key publication trends and thematic hotspots;
- Map influential sources, authors and institutions;

- Explore geographical and disciplinary patterns;
- Uncover the conceptual, intellectual and social structure of hydrogen economy research.

The insights generated here are intended to support researchers, policymakers and industry stakeholders seeking to align with or contribute to this rapidly growing field of knowledge and innovation.

2. Materials and Methods

2.1 Search Strategies

This bibliometric analysis aimed to examine global research trends and thematic developments related to the hydrogen economy. The Scopus database was selected as the primary data source due to its extensive indexing of peer-reviewed literature across scientific, technical, and social science disciplines.

The initial query retrieved 7,003 documents, covering the period from 2015 to 2026. To ensure the quality and comparability of the dataset, several inclusion filters were applied:

Document type: Only research articles and review papers were included, as these publication types offer the highest level of scholarly depth and methodological transparency.

Language: The search was restricted to English-language publications to ensure broader interpretability and consistency in bibliometric indicators.

Thematic coverage: Keywords used in the search string targeted multiple dimensions of the hydrogen economy, including its economic significance, policy frameworks, technological innovations, energy integration, and sustainability implications.

The final dataset provided a solid foundation for longitudinal and thematic analysis of how the hydrogen economy is addressed across diverse research fields.

2.2 Data Sources

A multi-software analytical framework was employed to extract, process, and visualise the bibliometric data:

Python (with the GeoPandas library) was used for data cleaning and geospatial visualisation, particularly for mapping the global distribution of research activities related to hydrogen.

R-Studio (version 2024.09.1+394), coupled with the bibliometrix package (Aria & Cuccurullo, 2017), enabled advanced bibliometric operations. These included thematic evolution analysis, dual-map overlays, and citation burst detection, offering a dynamic perspective on topic maturity, journal influence, and knowledge diffusion.

VOSviewer (version 1.6.20) was used to generate keyword co-occurrence networks across three distinct time periods. These visualisations facilitated the identification of conceptual clusters and their temporal progression, aligning with best practices in bibliometric mapping(Van Eck & Waltman, 2010).

By combining quantitative mapping with temporal segmentation, this methodology provided a comprehensive view of how hydrogen economy research has evolved in focus, scale, and interdisciplinarity.

Table 1. Search Criteria and Document Breakdown for Hydrogen Economy Research

Criteria	Details	Number of Documents (N° Doc)
Search Equation	"hydrogen economy" OR "green hydrogen economy" OR "hydrogen market" OR "hydrogen economic impact" OR "hydrogen industry" OR "hydrogen policy" OR "hydrogen energy economics" OR "hydrogen production economics" OR "hydrogen transition economics"	7003
Year Range	From 2015 to 2026 (as of 21 October 2025)	5203
Document Type	Only Articles and Reviews (A=3,315 R=760)	4075
Language	Only English	3747
Full Search	TITLE-ABS-KEY("hydrogen economy" OR "green hydrogen economy" OR "hydrogen	3747

Equation	market" OR "hydrogen economic impact" OR "hydrogen industry" OR "hydrogen policy" OR "hydrogen energy economics" OR "hydrogen production economics" OR "hydrogen transition economics") AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re")) AND (LIMIT-TO(LANGUAGE,"English")) AND PUBYEAR > 2015 AND PUBYEAR < 2026	

Source: Data collected using the Scopus database, as of 21 October 2025

The selected publication period of 2015 to 2026 was chosen to capture the most recent developments in hydrogen economy research. This timeframe reflects the post-Paris Agreement era, during which interest in hydrogen technologies has surged due to decarbonisation goals and energy transition policies. Analyzing this period allows for the identification of both established trends and emerging research frontiers.

The decision to limit the dataset to English-language publications was made to ensure consistency and comparability across the corpus, given that English is the prevailing language of global scientific communication. While this may exclude some region-specific research, it enhances access to internationally peer-reviewed findings and metrics.

Furthermore, the analysis focused exclusively on peer-reviewed articles and review papers, which offer greater methodological rigor and thematic depth than other publication types. Conference proceedings, book chapters, and grey literature were excluded to maintain quality standards and avoid inconsistencies in citation patterns and review practices.

The final dataset was exported in CSV format from the Scopus database and processed using a combination of analytical tools, including R-Studio (for bibliometric indicators and thematic evolution) and VOSviewer (for keyword network visualization and clustering).

2.3. Methodological Limitations and Validation

While this study adopted a rigorous and systematic bibliometric approach, it is essential to acknowledge several inherent limitations to ensure a balanced interpretation of the findings.

First, the exclusive use of the Scopus database, though justified by its comprehensive indexing and structured metadata, may have excluded relevant literature indexed only in other platforms such as Web of Science, Dimensions, or Google Scholar. This limitation may introduce selection bias, especially regarding emerging research from non-English-speaking countries or less internationally visible sources.

Second, restricting the dataset to English-language publications was intended to ensure analytical consistency and cross-comparability. However, this may have inadvertently excluded high-quality studies published in other languages, particularly those addressing regional hydrogen strategies or localised technological innovations.

Third, by including only peer-reviewed articles and review papers, the study ensured a focus on scholarly rigor. Nevertheless, conference proceedings, book chapters, and technical reports-often sources of early-stage or cutting-edge research-were excluded. This choice, while methodologically sound, may underrepresent nascent or interdisciplinary themes.

Additionally, reliance on quantitative bibliometric indicators such as the h-index, g-index, and citation counts has known limitations. These metrics are sensitive to field-specific citation behaviors, journal visibility, and self-citation practices, and may not accurately reflect the scientific quality or originality of individual publications.

To enhance the robustness of the analysis, several validation measures were implemented:

- The search strategy was refined iteratively through pilot queries to optimize both recall and precision.

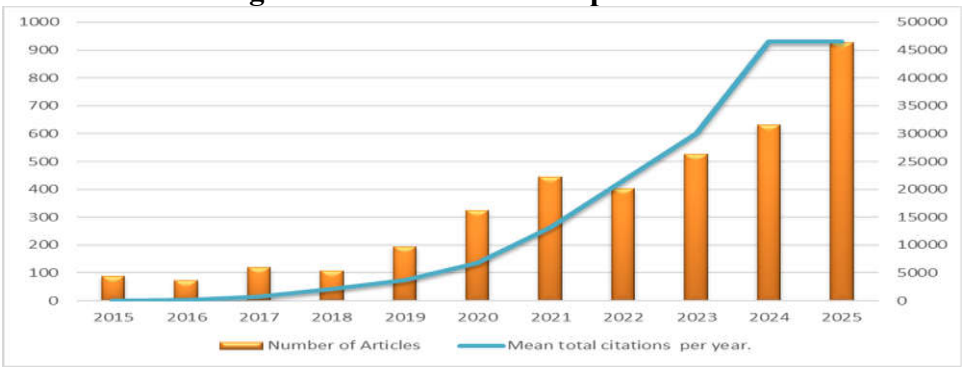
- Cross-validation was conducted between Python and R-Studio outputs to verify dataset integrity and metric reliability.
- Network visualizations generated using VOSviewer were manually reviewed to ensure the semantic and structural coherence of keyword clusters and citation linkages.

These measures mitigate—though do not eliminate—the inherent constraints of bibliometric research. Thus, the results should be interpreted within the context of these methodological boundaries.

3.Results

3.1. Overview

Figure 1. Annual scientific production

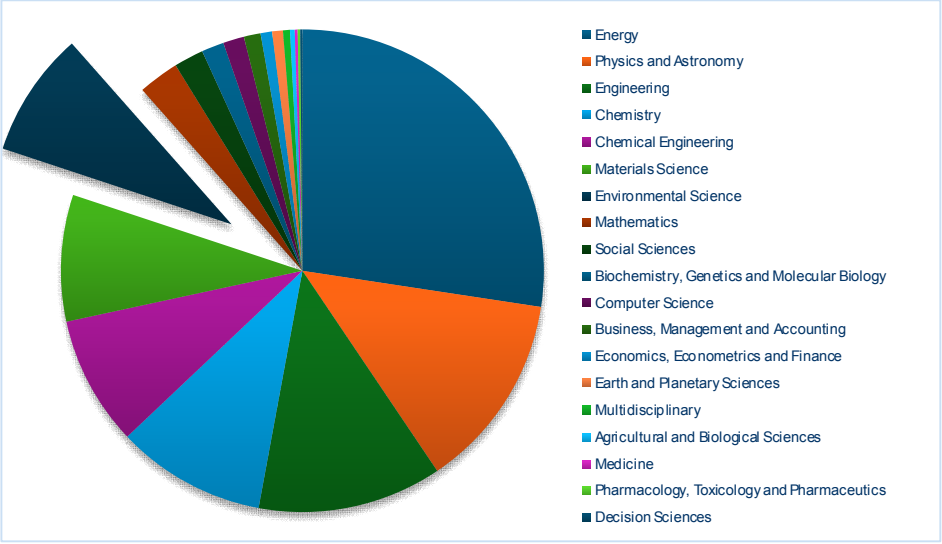


Source: Data obtained from Scopus and visualised using Microsoft Excel

Annual dynamics. **Figure 1** shows a clear inflection in the hydrogen-economy literature: after a relatively flat phase (2015–2020), output and impact both accelerate from 2021 onward, peaking in 2024 (632 articles; 73.67 citations/article). This step-change aligns with policy stimuli and funding waves tied to post-pandemic green-recovery packages and national hydrogen roadmaps, which typically translate into sharp, short-lag surges in publications. The slight dip in average citations in 2025 is expected statistically (shorter citation window for recent papers) rather than a true decline in influence; citation rates generally converge upward over 12–24 months. Comparable surges and timing have been reported by large-scope bibliometric reviews

that also observe a post-2020 acceleration and a consolidation of green-hydrogen topics. (Osman et al., 2025)

Figure 2 . Documents by subjects area



Source: Data obtained from Scopus and visualised using Microsoft Excel

Figure 2 illustrates the subject area distribution of publications on the hydrogen economy, revealing the deeply interdisciplinary nature of research in this domain. The Energy category dominates with 2,347 documents, underscoring hydrogen's pivotal role in advancing global clean energy transitions. Substantial contributions from Physics and Astronomy (1,127) and Engineering (1,058) indicate that hydrogen research is largely driven by experimental and technical innovations, particularly in thermodynamics, material engineering, and system optimisation for hydrogen production, conversion, and storage. Disciplines such as Chemistry (858) and Chemical Engineering (744) further reinforce the scientific foundations of the field, focusing on catalytic reactions, electrochemical processes, and the design of high-efficiency materials.

Meanwhile, Materials Science (726) and Environmental Science (719) demonstrate the growing importance of sustainable

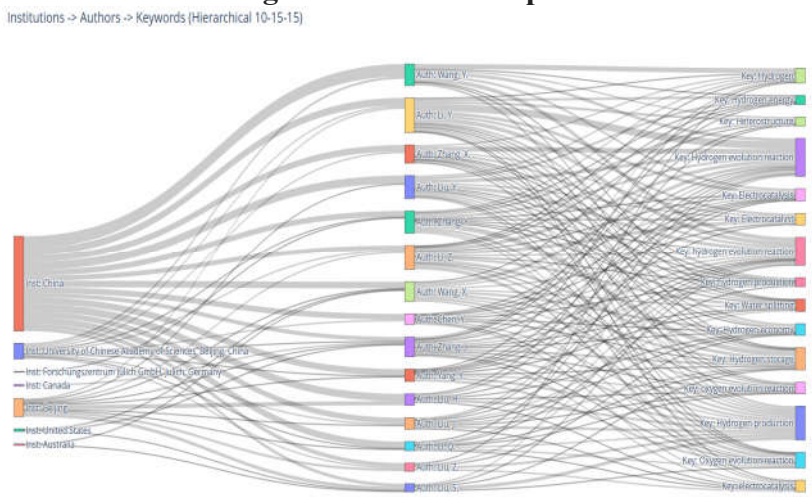
material development and environmental performance evaluation within hydrogen research. The inclusion of Mathematics (234) and Computer Science (121) reflects the increasing integration of modelling, machine learning, and data analytics to optimise hydrogen systems. Furthermore, contributions from the Social Sciences (171), Economics (66), and Business and Management (97) highlight an emerging interest in the economic, policy, and societal implications of hydrogen technologies. Although less represented, disciplines such as Medicine, Pharmacology, and Psychology indicate the expanding influence of hydrogen research beyond traditional scientific domains. Collectively, this distribution confirms that hydrogen economy research has evolved into a multidisciplinary ecosystem, uniting the physical, environmental, and social sciences to drive innovation and global sustainability. (Kar et al., 2022a)

Comparative positioning vs. prior bibliometrics. Our patterns are consistent with (i) a field-level consolidation around production, storage, and fuel-cell utilisation; (ii) the central editorial role of the *International Journal of Hydrogen Energy* in diffusing the literature; and (iii) an expanded post-2020 research front on green hydrogen**.** Kar et al. (2022) mapped hydrogen-economy research over five decades and likewise identified IJHE as a pivotal outlet and the same triad of thematic pillars (production–storage–applications). A 2024–2025 wave of reviews further corroborates the green-hydrogen shift and the broadening to techno-economic and sustainability lenses.(Kar et al., 2022b)

Figure 3 illustrates a Three-field plot that visualises the relationships between institutions, authors, and keywords in the research field of the hydrogen economy. The diagram highlights a clear dominance of Chinese institutions, with "Inst: China" showing the largest flow, indicating China's significant contribution to this area of study. Prominent institutions such as the University of Chinese Academy of Sciences stand out, reflecting China's central role in the field. Additionally, authors

such as Wang, Y., Li, Y., and Zhang, X. are closely associated with key topics like "Hydrogen production", "Water splitting", and "Hydrogen evolution reaction". The diagram also illustrates the global presence of research from Germany, the United States, Canada, and Australia, though their contributions are smaller compared to China's. The keywords reveal that the focus of research is primarily on hydrogen generation methods, energy applications, and addressing challenges like "Hydrogen storage". This visualisation underscores the interconnected efforts of institutions, authors, and specific research areas that drive the advancement of hydrogen economy research.

Figure 3. Three-field plot.



Source: Data obtained from Scopus and analysed using Bibliometrix and visualised with Python

3.2. Sources

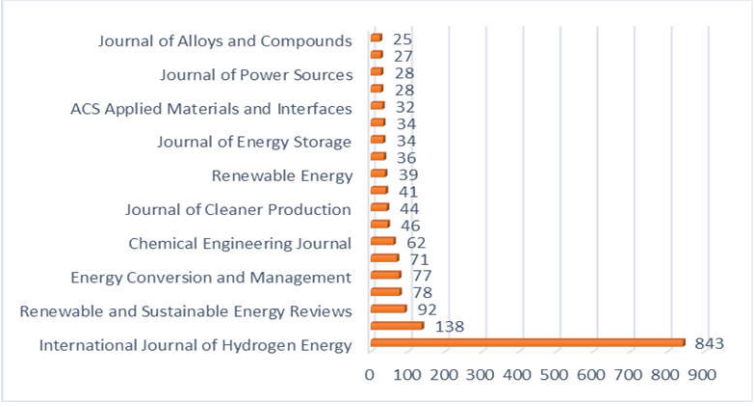
Figure 4 highlights the leading journals contributing to research in the field of hydrogen economy and renewable energy, based on the number of published articles. The International Journal of Hydrogen Energy dominates with a total of 843 articles, positioning it as the foremost journal in this domain. Following closely is Energies with 138 articles, reflecting its strong presence in the scientific discourse on green hydrogen and energy solutions. Other significant contributors include

Renewable and Sustainable Energy Reviews (92 articles), Applied Energy (78 articles), and Energy Conversion and Management (77 articles), which showcase a consistent volume of publications, further cementing their importance in advancing hydrogen-related research.

The list also features journals like Fuel (46 articles), Journal of Cleaner Production (44 articles), and Sustainability Switzerland (41 articles), indicating that these sources are integral in disseminating studies on sustainable energy and hydrogen technologies. Renewable Energy (39 articles) and Journal of Materials Chemistry A (36 articles) are also noteworthy for their contributions, though they publish fewer articles compared to the aforementioned leaders.

This distribution of articles underscores the growing interest and focus on hydrogen economy research across a range of high-impact journals. The variety of journals highlights the multidimensional nature of hydrogen research, spanning across energy production, materials science, catalysis, and environmental sustainability. The concentration of articles in these key journals suggests that they are pivotal in shaping the current research landscape and serve as primary platforms for advancing the technological and scientific understanding of hydrogen as a clean energy source.

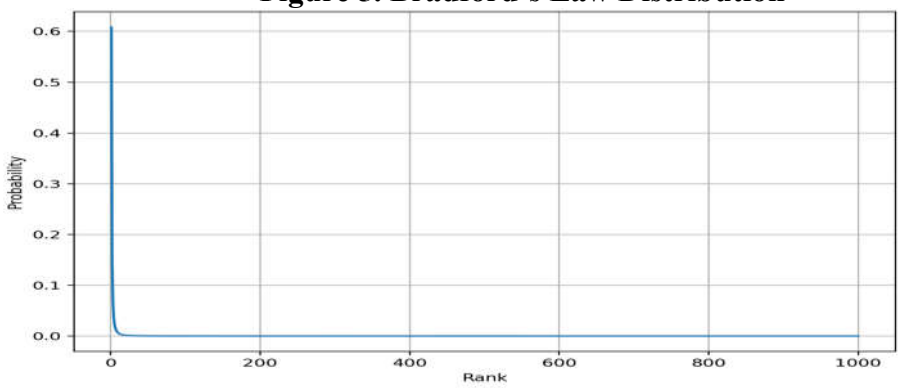
Figure 4. Leading Sources in Hydrogen Economy Research



Source: Data obtained from Scopus and visualised using Microsoft Excel

Figure 5 illustrates the distribution of scientific publications according to *Bradford's Law*, which highlights the concentration of articles within a small number of core journals. As shown, the curve initially rises steeply, reflecting the substantial contribution of a few key journals at the lower ranks. These journals produce the majority of publications in the field, suggesting their central role in disseminating knowledge. However, as the rank increases, the curve declines sharply, indicating that a large number of journals contribute significantly fewer articles. This creates a long, flat tail that represents the numerous peripheral journals with minimal impact on the overall body of research. The graph exemplifies the *"vital few and trivial many"* principle, where a small number of core sources dominate the literature, while the majority of journals contribute only a small fraction of the total publications. This distribution underscores the importance of focusing on core journals for comprehensive coverage of key research areas.

Figure 5. Bradford's Law Distribution



Source: Data obtained from Scopus and analysed using Bibliometrix and visualised with Python

Table 2 presents an analysis of the local impact of various sources in the field of hydrogen economy research, using bibliometric indices such as the h-index, g-index, m-index, total citations (TC), number of publications (NP), and the starting publication year (PY_start). The h-index refers to a collection of papers that have at least h citations, where each article in the set

has been cited at least h times. The g-index is based on the number of citations, where a journal's set of papers must have at least g^2 citations. The m-index measures the relationship between the h-index and the number of years since the first publication by the author.

The International Journal of Hydrogen Energy stands out with an impressive h-index of 100, g-index of 179, and m-index of 11.11, reflecting its significant impact on the field, with 42,565 total citations from 812 publications since 2016. Other noteworthy journals include Renewable and Sustainable Energy Reviews with an h-index of 34, g-index of 71, and m-index of 3.78, as well as Energy Conversion and Management with h-index of 33, g-index of 72, and m-index of 4.125. These journals demonstrate a solid contribution to the field, with substantial citations and publications.

Journals like Applied Energy and Chemical Engineering Journal also show strong bibliometric indicators, with h-indices of 32 and 31, respectively, reflecting their growing influence in hydrogen economy research. On the other hand, journals like Fuel, Journal of Materials Chemistry A, and Energy and Environmental Science, with h-indices ranging from 22 to 24, while slightly lower, still play significant roles in advancing research in energy technologies.

This analysis underscores how certain journals, particularly those like the International Journal of Hydrogen Energy, serve as major contributors to the scientific literature in the field of hydrogen economy, providing essential resources for researchers seeking impactful and relevant works.

Table 2. Sources' local impact.

Source	h_Index	g_Index	m_Index	TC	NP	PY_Start
International Journal of Hydrogen Energy	100	179	11,11	42565	812	2016

Renewable and Sustainable Energy Reviews	34	71	3,78	8475	71	2016
Energy Conversion and Management	33	72	4,125	5320	74	2017
Applied Energy	32	52	4	2806	78	2017
Chemical Engineering Journal	31	54	5,17	2944	62	2019
Energies	29	56	3,625	3639	138	2017
Journal of Cleaner Production	25	43	3,57	3012	43	2018
Journal of Materials Chemistry A	24	36	2,67	2114	36	2016
Energy and Environmental Science	24	26	3	5626	26	2017
Fuel	22	37	4,4	1403	38	2020

Source: Data obtained from Scopus and analysed using Bibliometrix in R for bibliometric indices

3.3. Countries

Figures 6 and 7 illustrate the geographical distribution of research on the hydrogen economy, revealing pronounced disparities in publication output and reflecting the strategic priorities of different national research systems. China dominates with 1,191 publications, a position that mirrors its sustained governmental investment in hydrogen technologies under its 14th Five-Year Plan and the Made in China 2025 framework. Such policy-driven funding has fostered a dense national research network linking universities, state laboratories, and industrial

clusters—an ecosystem similarly noted by Rodríguez-Aburto et al. (Rodríguez-Aburto et al., 2024)

The United States, ranking second with 404 publications, remains a central actor, propelled by Department of Energy initiatives such as H2@Scale and public-private partnerships that prioritise fuel-cell integration and renewable hydrogen infrastructure. India follows with 326 publications, reflecting a strong governmental push through the National Hydrogen Mission and international collaborations aimed at decarbonising industry and transport sectors. These three nations jointly account for more than 40 % of global output, underscoring their leadership in both technological innovation and policy commitment.

Across Europe, publication activity is distributed among the United Kingdom (292), Germany (287), and South Korea (291)—the latter acting as Asia's secondary hub after China. In Europe, long-standing funding frameworks such as Horizon 2020 and Clean Hydrogen JU have encouraged cross-border collaboration, resulting in high-impact clusters around fuel-cell development, electrolyser efficiency, and hydrogen storage materials. Germany's sustained investment through its National Hydrogen Strategy (2020) continues to position it at the forefront of applied hydrogen engineering (Kar et al., 2022b).

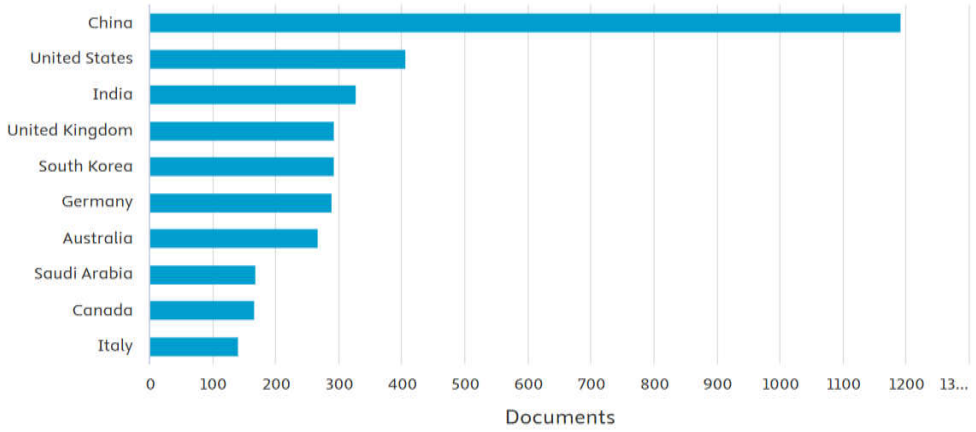
In the Middle East, Saudi Arabia (166 publications) has emerged as a regional leader, aligning its scientific agenda with Vision 2030 and flagship projects such as NEOM's Green Hydrogen Plant. The United Arab Emirates (41 publications) and Qatar (25) also demonstrate rising engagement, reflecting a strategic pivot from fossil-fuel dependence toward renewable-energy diversification(Osman et al., 2025).

Among emerging economies, Brazil (52), Egypt (50), and Pakistan (50) signal a growing south-south dynamic where hydrogen research is integrated into broader sustainability and industrial-modernisation policies. The increasing presence of Malaysia (86) and Poland (87) further illustrates a diffusion of

hydrogen-related research capacity into mid-income and transitional economies—an encouraging sign of the field's globalisation beyond traditional scientific powerhouses.

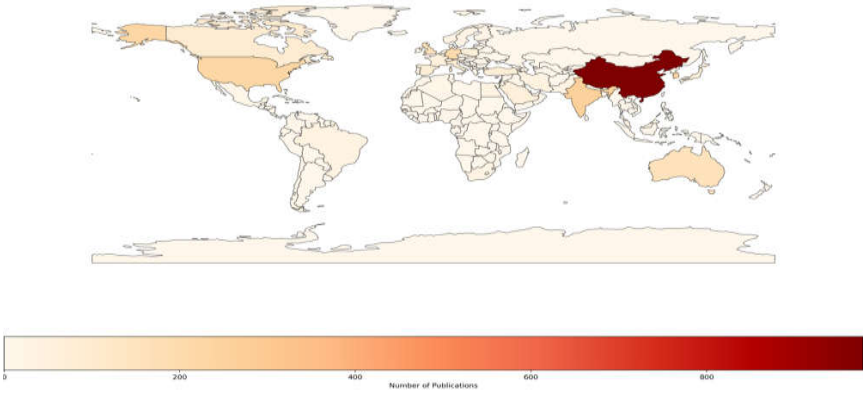
Collectively, these findings reinforce the existence of a two-tiered global landscape: a core group of nations (China, U.S., Germany, Japan, Korea) that set the research agenda through large-scale projects and funding mechanisms, and a rapidly expanding periphery of countries investing in policy-driven, application-oriented studies. The geographic concentration observed here parallels earlier bibliometric mappings that highlight the same asymmetry between established and emerging contributors(Kar et al., 2022a; Rodríguez-Aburto et al., 2024). Nevertheless, the appearance of new actors from Latin America, Africa, and South Asia indicates a more inclusive evolution of hydrogen research—suggesting that future growth will likely stem from cross-regional cooperation and knowledge transfer initiatives.

Figure 6. Corresponding authors' countries.



Source: Data obtained from Scopus and analysed using Bibliometrix in R for bibliometric indices

Figure 7. Country scientific production.

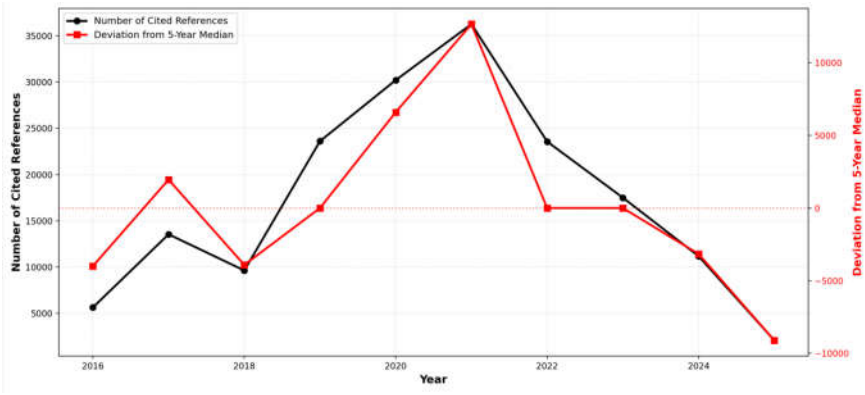


Source**:** Data obtained from Scopus and visualised using Python, illustrating the distribution of hydrogen economy research publications by country.

3.4. Documents

The figure illustrating *Reference Spectroscopy: Citation Analysis* provides a comprehensive overview of citation trends within the hydrogen economy research domain over time, offering valuable insight into the evolution, maturity, and eventual saturation of the field. The black line represents the *number of cited references* per year, while the red line captures the *deviation from the five-year median*, thus revealing fluctuations relative to the field's expected citation behaviour.

Figure 8. Reference spectroscopy: Citation Analysis Cited References Vs Deviation from 5-Year Median

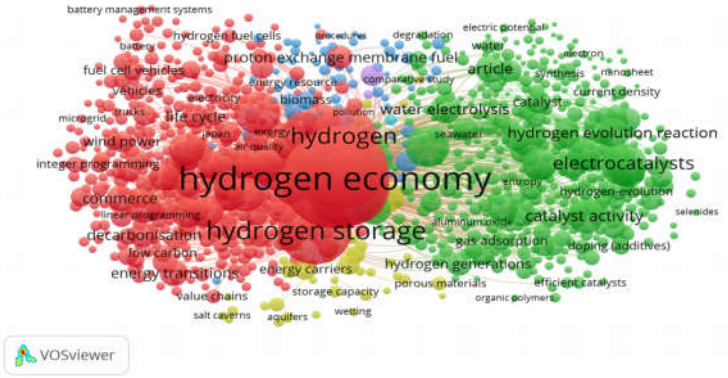


Source: Data visualisation created using Python with relevant libraries for citation analysis and reference spectroscopy.

From 2016 to 2018, the data reflect a formative stage marked by inconsistency and limited scholarly attention, as the number of citations oscillated with modest deviations from the median. This period likely represents the early establishment of the research topic, during which scientific interest was emerging but not yet consolidated.

A significant transformation occurs between 2019 and 2021, a period characterised by rapid escalation in citations and a sharp positive deviation, indicating extraordinary academic activity. The year 2021, in particular, stands out as the field's "golden year," witnessing an unprecedented surge in citation volume — a clear sign of heightened global interest and intensive publication output. However, this momentum did not persist. From 2022 onwards, the trend begins a pronounced decline, accompanied by a shift in deviation towards neutrality and eventually into negative territory by 2024–2025. This suggests a gradual normalisation followed by a cooling phase, where scholarly focus may have shifted towards emerging or adjacent energy technologies. Overall, the figure encapsulates a typical research lifecycle: an initial phase of exploration, a phase of exponential growth and heightened visibility, and a final phase of stabilisation or decline, signifying the field's transition from a rapidly expanding frontier to a more mature area of inquiry.

Figure 9. Most-frequent words.



Source: Created by the author using VOSviewer, based on data retrieved from the Scopus database.

The keyword co-occurrence network map (Figure 9), generated using VOSviewer based on Scopus-indexed publications, provides a comprehensive visualisation of the thematic structure in the hydrogen economy literature. In this map, node size represents keyword frequency, link thickness reflects co-occurrence strength, and colours identify distinct clusters of related research themes. The proximity between nodes indicates conceptual relatedness, allowing the identification of interlinked and isolated knowledge domains.

Building upon recent bibliometric analyses (e.g., Osman et al., 2025; Rodríguez-Aburto et al., 2024; Roucham & Zaghdoud, 2025), this study offers a more granular clustering scheme that reveals four prominent and thematically distinct research areas, in contrast to earlier models that primarily focused on production, storage, and utilisation triads. These clusters not only corroborate but also expand on previous findings by illustrating nuanced thematic divisions and emerging trends in the hydrogen economy domain.

Cluster 1 – Economics and Applications (Red) :This is the largest and most central cluster, dominated by terms such as hydrogen economy, hydrogen storage, fuel cells, and decarbonisation. It encompasses literature that addresses the practical deployment of hydrogen technologies, with strong emphasis on fuel cell vehicles, hybrid systems, economic viability, and life cycle analysis. This application-driven focus is consistent with the findings of Rodríguez-Aburto et al. (2024), who identified a growing emphasis on economic and innovation impacts in green hydrogen research.

This cluster effectively answers the question: "Why and how should we use hydrogen?", and reveals the strategic role hydrogen plays in the global energy transition.

Cluster 2 – Hydrogen Production Science (Green) :This cluster aggregates foundational research on hydrogen generation, electrocatalysis, hydrogen evolution reaction, electrolysis, and catalyst activity. The dominance of electrochemical production

techniques suggests a sustained focus on improving the efficiency and cost-effectiveness of hydrogen production, particularly from renewable sources.

The increasing density of this cluster in recent years aligns with trends reported by Osman et al. (2025), who observed a significant surge in green hydrogen research driven by material innovation and nanocatalyst development.

Cluster 3 – Storage Materials and Techniques (Yellow) : Storage remains a critical bottleneck in the hydrogen value chain. This cluster captures research focused on porous materials, gas adsorption, storage capacity, and geological storage solutions such as salt caverns and aquifers. It bridges the gap between production and application by exploring materials science-based innovations that enable scalable and safe hydrogen storage.

Despite its importance, the spatial separation between this cluster and others-especially the technological (blue) cluster-may signal a research fragmentation that warrants greater integration, as noted by Roucham and Zaghdoud (2025) in their analysis of BRICS-based hydrogen research networks.(Roucham & Zaghdoud, 2025)

Cluster 4 – Fuel Cell and Electrolyser Technologies (Blue) : This engineering-focused cluster includes keywords like proton exchange membrane fuel cell (PEMFC), electrolytic cell, and efficiency. It represents the link between hydrogen production and practical deployment, particularly through device innovation. The cluster underscores the need for improvements in system-level performance and cost reduction in hydrogen energy conversion technologies.

The network demonstrates a clear interdependency between foundational science (green), storage innovation (yellow), device engineering (blue), and real-world applications (red). However, the weak linkages between some clusters-particularly between material science (yellow) and system-level technologies (blue)-suggest a need for greater interdisciplinary collaboration.

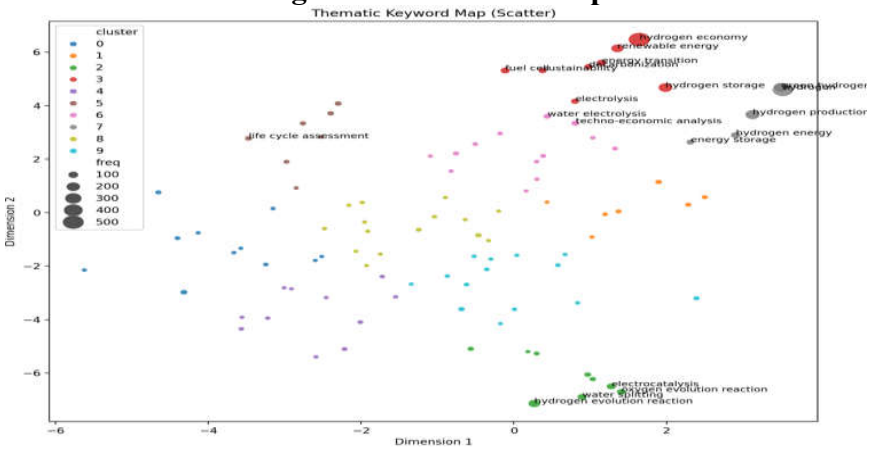
Strategically, future research agendas should promote cross-cluster synergies, fostering projects that simultaneously address catalyst efficiency, storage capacity, and system integration. As Rodríguez-Aburto et al. (2024) and Osman et al. (2025) suggest, the acceleration of a viable hydrogen economy depends not only on technological advancement, but also on bridging thematic and disciplinary gaps.

3.5. Conceptual Structure

Figure 10 presents a conceptual keyword map derived from a two-dimensional scatterplot clustering of thematic terms associated with hydrogen economy literature. Unlike co-occurrence maps that highlight structural keyword relationships, this conceptual map reveals the functional orientation of research clusters, providing insight into how research themes are positioned cognitively and topologically within the field.

Using frequency-weighted clustering, the map displays keywords as nodes where size reflects frequency, colour represents thematic grouping, and proximity suggests conceptual similarity. The spatial arrangement illustrates the bipolar nature of hydrogen economy research, balancing between foundational scientific inquiry and strategic, policy-driven discourse.

Figure 10. Thematic map



Source: Created by the author using Python, based on data retrieved from the Scopus database.

Cluster 0 – Strategic and Economic Drivers of Hydrogen (Top Right):This cluster, the most dominant in both frequency and central positioning, includes terms such as *hydrogen economy*, *renewable energy*, *energy transition*, and *decarbonisation*. It encapsulates the strategic rationale for hydrogen integration into future energy systems, reflecting its role in policy frameworks and sustainability agendas.

As noted by Rodríguez-Aburto et al. (2024), this thematic axis demonstrates the growing intersection between hydrogen technologies and macroeconomic planning, especially in contexts like climate mitigation, energy diversification, and national energy security.

Cluster 5 – Scientific Foundations of Hydrogen Production (Bottom Right): Located distinctly at the lower right, this cluster includes core scientific terms such as *electrocatalysis*, *hydrogen evolution reaction*, and *oxygen evolution reaction*. These keywords reflect ongoing research into electrochemical mechanisms that underpin green hydrogen production.

This cluster corresponds to the deep scientific domain of the field, focused on catalyst design, reaction kinetics, and efficiency improvement—consistent with the trends highlighted in Osman et al. (2025), who identified a surge in nanomaterial-based hydrogen generation studies.

Cluster 3 – Applied Integration and Feasibility Studies (Right Center): This cluster acts as a conceptual bridge between science and strategy. It includes keywords like *hydrogen production*, *green hydrogen*, *hydrogen storage*, and *energy storage*. These terms capture research that translates scientific advancements into integrated energy solutions, emphasizing system-level feasibility and deployment.

It reflects the "meso-level" of hydrogen research—where technical performance, grid integration, and storage logistics intersect. The central positioning of this cluster echoes findings by Roucham & Zaghdoud (2025), who emphasised the

importance of cross-sector integration in BRICS hydrogen innovation.

Cluster 2 – Techno-Economic and Electrolysis Technologies (Center Right): The pink cluster gathers terms related to *electrolysis*, *water electrolysis*, and *techno-economic analysis*, indicating focus on both technological advancement and economic feasibility.

This domain serves as a translational zone, examining how electrochemical innovations can be scaled economically. It highlights cost modelling, system efficiency, and deployment scenarios—elements central to hydrogen investment strategies and policy design.

Cluster 1 – Environmental Assessment and Sustainability Metrics (Far Left): Positioned at the left edge of the map, the brown cluster includes *life cycle assessment* (LCA), a critical tool for evaluating the environmental footprint of hydrogen technologies. This cluster, although less densely populated, signals the rising emphasis on environmental accountability and full-spectrum sustainability assessment. As noted in bibliometric reviews(Yang et al., 2024), LCA is increasingly employed to compare hydrogen pathways and validate "green" labels for production and storage systems.

Together, these clusters illustrate a cognitive dualism in hydrogen economy research: on one hand, fundamental scientific exploration (Cluster 5); on the other, strategic-economic framing and deployment models (Cluster 0). Bridging domains such as Clusters 3 and 2 represent translational zones, essential for aligning innovation with impact.

3.6. Intellectual Structure

Figure 11 illustrates the co-citation network of cited references, unveiling the intellectual architecture underpinning the hydrogen economy research domain. Unlike keyword analyses that depict thematic evolution, this co-citation mapping identifies the intellectual roots and schools of thought shaping the scientific discourse. Each node represents a frequently co-cited

reference, with its size corresponding to citation impact. The coloured clusters delineate groups of references that are often cited together, reflecting distinct research paradigms and epistemic communities.

The network reveals four major intellectual clusters that constitute the conceptual foundations of hydrogen economy research:

(a) The Red Cluster – Policy and Strategic Roadmapping : Located on the left side of the network, this cluster aggregates highly influential policy-oriented works such as The Future of Hydrogen (International Energy Agency, 2019) and Hydrogen Roadmap Europe (2020). These publications form the strategic backbone of the hydrogen discourse, addressing macro-level questions related to governance, investment frameworks, and market deployment. This intellectual stream defines the "why and how" of hydrogen adoption, aligning with the global energy transition agenda rather than experimental science.

(b) The Blue Cluster – Sustainable Hydrogen Production Science :Dominating the right section, this cluster encapsulates seminal scientific contributions from researchers such as John A. Turner and Steven Chu(Chu & Majumdar, 2012; Turner, 2004), focusing on solar water splitting, electrocatalysis, and photoelectrochemical hydrogen generation. It represents the core scientific paradigm of green hydrogen production and advances the understanding of materials, efficiency, and energy conversion mechanisms. Similar research trajectories were identified by Kar et al, who reported a growing convergence between material chemistry and renewable energy physics.

(c) The Yellow Cluster – Hydrogen Storage Science : Positioned in the upper region, this cluster centres on material-based storage solutions, drawing heavily from the pioneering work of Louis Schlapbach and colleagues on metal hydrides and solid-state storage. It represents the engineering frontier addressing one of the hydrogen economy's enduring challenges: achieving safe, efficient, and scalable hydrogen storage. These

studies highlight how advances in materials science directly condition the feasibility of large-scale hydrogen deployment.

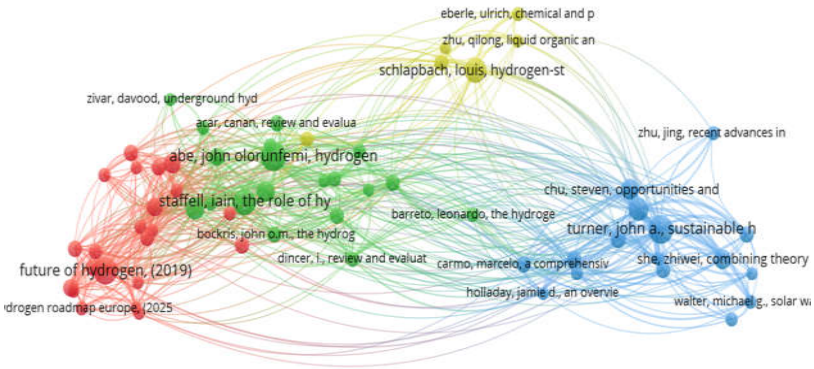
(d) The Green Cluster – Foundational Reviews and Integrative Frameworks :Acting as an intellectual bridge, this central cluster aggregates comprehensive review papers and conceptual syntheses authored by figures such as John O. M. Bockris and Ibrahim Dincer.(Ben Jemaa et al., 2017) These works provide theoretical cohesion to the field, integrating perspectives from technology, sustainability, and energy policy. They serve as entry points for new researchers and connect the more specialised pillars-policy, production, and storage—into a coherent knowledge framework.

In essence, the co-citation structure underscores that hydrogen economy research rests on interconnected yet differentiated knowledge pillars:

- strategic governance and policy design (Red),
- scientific innovation in production technologies (Blue),
- material-based storage development (Yellow),
- and integrative theoretical frameworks (Green).

This intellectual configuration evidences a mature and interdisciplinary research field, where scientific advancement and strategic policymaking evolve in parallel to support the global transition towards sustainable hydrogen energy**.**

Figure 11. Co-citation Network of Cited References in Hydrogen Economy Research



Source: Created by the author using VOSviewer, based on data retrieved from the Scopus database

3.7. Global Collaboration Network in Hydrogen Research

Figure 12 depicts the international collaboration network among the most productive countries in hydrogen-related research, generated using VOSviewer from Scopus data. Each node represents a country, the node size corresponds to the volume of publications, and the thickness of the connecting lines reflects the total link strength—that is, the intensity of co-authorship between countries. Distinct colours indicate collaboration clusters that share strong interconnections and similar research orientations.

Overall, the network exhibits a global collaboration rate of 31.83%, indicating that nearly one-third of all publications in the field are produced through international partnerships. This proportion highlights a moderate yet steadily increasing level of scientific cooperation, reflecting the global relevance of hydrogen research and the growing need for cross-border expertise to tackle complex energy challenges.

The network displays a highly centralised global structure dominated by a few key scientific hubs. China occupies the most prominent position, with the largest node and the highest total-link strength, signifying its role as the principal driver of international cooperation in hydrogen research. Its extensive partnerships with the United States, Germany, and South Korea highlight a dense web of bilateral and multilateral projects, confirming China's status as both the most productive and the most connected nation in the field.

The United States and the United Kingdom emerge as the main Western bridges in this network. Although their publication output is lower than China's, both countries exhibit strong collaborative ties across continents, particularly with European and Asia–Pacific partners. This bridging function positions them as trans-regional mediators, facilitating knowledge exchange between research blocs and strengthening the global research ecosystem.

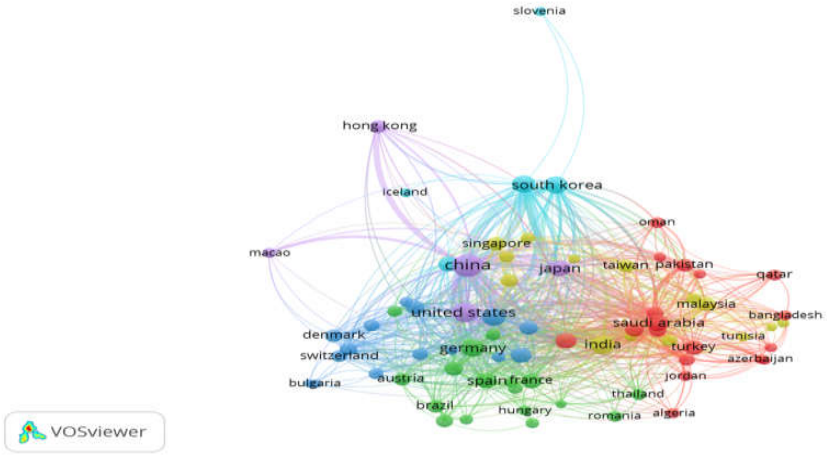
Australia and Saudi Arabia demonstrate outstanding collaboration efficiency. Despite a relatively modest number of documents, both countries achieve very high link strengths, indicating that their research is deeply embedded in international consortia and frequently co-authored with top institutions abroad. Saudi Arabia, in particular, acts as a collaborative hub within the Middle East, connecting Asian and European partners and reflecting its strategic investment in hydrogen under the Vision 2030 agenda.

Among the emerging Asian powers, India, Japan, and South Korea form a dense triangular network with China, underscoring Asia's ascendancy in green-hydrogen technologies. These nations contribute substantial publication volumes and maintain balanced outward collaborations, signalling a shift of research gravity from the West to the East.

Within Europe, Germany, Spain, France, and Italy remain key contributors, sustaining a coherent and mature regional research base supported by EU programmes such as Horizon Europe and the Clean Hydrogen Joint Undertaking. Their inter-European clustering (green nodes) indicates a strong tradition of intra-regional collaboration complemented by global linkages to the United States and China.

Peripheral yet active participants-such as Malaysia, Turkey, Qatar, and the United Arab Emirates-illustrate a growing diversification of research actors, reflecting the globalisation of hydrogen research and the increasing involvement of developing economies in high-impact collaborations.

Figure 12. International Collaboration Network among Countries in Hydrogen Research



Source: Created by the author using VOSviewer, based on data retrieved from the Scopus database

4. Discussion

This study provides a detailed bibliometric examination of the global research landscape surrounding the hydrogen economy, using a robust methodological framework that integrates data from Scopus with analytical tools such as Python, R-Studio, and VOSviewer. The findings highlight not only the volume and growth trajectory of hydrogen-related publications but also reveal the thematic, conceptual, intellectual, and collaborative structures shaping the field.

The surge in publication output post-2020, particularly peaking in 2024, reflects intensified governmental and industrial investment aligned with global decarbonisation goals and post-pandemic recovery agendas. This is consistent with prior analyses (Osman et al., 2025; Kar et al., 2022), which noted the influence of policy instruments like the EU Green Deal and national hydrogen roadmaps. The predominance of journal articles within key publications such as the International Journal of Hydrogen Energy indicates a concentrated effort in

disseminating high-impact research through a few dominant outlets, in line with Bradford's Law.

The disciplinary distribution, led by energy, physics, engineering, and chemistry, confirms that hydrogen research is both technically intensive and deeply interdisciplinary. Notably, emerging contributions from computer science and economics suggest a growing integration of data analytics and policy modelling in hydrogen systems, reinforcing the sector's systemic complexity.

Conceptually, the field demonstrates a bipolar structure: fundamental science (e.g., electrocatalysis, hydrogen evolution) anchors one pole, while economic, policy, and strategic frameworks (e.g., hydrogen economy, decarbonisation, energy transition) form the other. The presence of intermediary clusters—such as techno-economic assessments and system integration studies—highlights the evolving maturity of the field as it shifts from isolated experimentation to systemic deployment.

The intellectual structure of the field, as revealed through co-citation analysis, further validates this duality. Influential clusters include foundational scientific work (Turner, Chu), strategic roadmaps (IEA, Hydrogen Europe), and integrative reviews (Dincer, Bockris). These diverse schools of thought contribute to a coherent yet multifaceted knowledge base.

Geographically, the data confirms China's dominance in both output and network centrality, followed by the United States, India, and key European nations. However, the increasing visibility of countries like Saudi Arabia, Brazil, and Malaysia suggests a decentralisation trend and the globalisation of hydrogen research. This aligns with recent observations (Rodríguez-Aburto et al., 2024) that point to expanding south-south and east-west collaborations.

While the results are robust, the study also recognises methodological limitations, including database scope, language bias, and metric sensitivity. These were mitigated through cross-

validation procedures and careful filtering. Still, future research should consider multi-database triangulation and more inclusive linguistic policies to capture a broader scope of hydrogen research.

5. Conclusion

This study provided a comprehensive bibliometric analysis of global research on the hydrogen economy from 2015 to 2026. the research successfully mapped the structural, thematic, and intellectual foundations of the field. The findings demonstrate a pronounced acceleration in hydrogen-related research post-2020, particularly in response to global climate commitments, technological breakthroughs, and policy-driven funding mechanisms.

The results highlight several key patterns:

- A bipolar conceptual structure, where fundamental scientific research on hydrogen production technologies coexists with strategic and economic discourse on energy transitions.
- A highly concentrated publication landscape, dominated by journals like the International Journal of Hydrogen Energy.
- Geopolitical asymmetries, with countries such as China, the United States, and Germany leading in research output and collaboration networks, but with rising contributions from emerging economies such as India, Saudi Arabia, and Brazil.
- Interdisciplinary convergence, evidenced by the integration of environmental science, engineering, economics, and computational methods in hydrogen research.
- Despite the robust methodology, this study acknowledges certain limitations, including language and database scope, and encourages triangulation with other data sources (e.g., Web of Science, Dimensions) in future studies. Moreover, emerging fields such as digital hydrogen modelling, AI-driven optimisation, and regional policy benchmarking warrant deeper exploration.

Recommendations for Future Research

- To further advance the field of hydrogen economy research, the following directions are proposed:
- Expand Data Sources: Incorporate multi-database approaches (e.g., WoS, Dimensions, IEEE Xplore) to enhance coverage and diversity of publications.
- Include Multilingual Literature: Analyze non-English sources to capture region-specific innovations, particularly from Latin America, Africa, and East Asia.
- Longitudinal Cluster Tracking: Conduct dynamic clustering over shorter intervals (e.g., 2-year windows) to detect micro-trends and research front shifts.
- Integrate Patent Analysis: Combine bibliometric and patent data to assess technological maturity and commercialization pathways.
- Map Policy and Industry Linkages: Use scientometric-policy analysis to evaluate how academic research aligns with or influences national hydrogen strategies.

Footnotes

Ben Jemaa, R., Mansouri, R., Boukholda, I., & Bellagi, A. (2017). Energy and exergy investigation of R1234ze as R134a replacement in vapor compression chillers. *International Journal of Hydrogen Energy*, *42*(17), 12877–12887. https://doi.org/10.1016/j.ijhydene.2016.12.010

Chu, S., & Majumdar, A. (2012). Opportunities and challenges for a sustainable energy future. *Nature*, *488*(7411), 294–303. https://doi.org/10.1038/nature11475

Hydrogen production – Global Hydrogen Review 2024 – Analysis. (2024). IEA. https://www.iea.org/reports/global-hydrogen-review-2024/hydrogen-production

International Energy Agency. (2019). *The Future of Hydrogen: Seizing today's opportunities*. OECD. https://doi.org/10.1787/1e0514c4-en

Jeje, S. O., Marazani, T., Obiko, J. O., & Shongwe, M. B. (2024). Advancing the hydrogen production economy: A comprehensive review of technologies, sustainability, and future prospects.

International Journal of Hydrogen Energy, *78*, 642–661. https://doi.org/10.1016/j.ijhydene.2024.06.344

Kar, S. K., Harichandan, S., & Roy, B. (2022a). Bibliometric analysis of the research on hydrogen economy: An analysis of current findings and roadmap ahead. *International Journal of Hydrogen Energy*, *47*(20), 10803–10824. https://doi.org/10.1016/j.ijhydene.2022.01.137

Kar, S. K., Harichandan, S., & Roy, B. (2022b). Bibliometric analysis of the research on hydrogen economy: An analysis of current findings and roadmap ahead. *International Journal of Hydrogen Energy*, *47*(20), 10803–10824. https://doi.org/10.1016/j.ijhydene.2022.01.137

Osman, S. H., Mat Yatim, N. S., Jehan Elham, O. S., Shaari, N., & Zakaria, Z. (2025). Three decades of hydrogen energy research: A bibliometric analysis on the evolution of green hydrogen technologies. *Sustainable Energy & Fuels*, *9*(12), 3182–3202. https://doi.org/10.1039/D5SE00254K

Rodríguez-Aburto, C., Poma-García, J., Montaño-Pisfil, J., Morcillo-Valdivia, P., Oyanguren-Ramirez, F., Santos-Mejia, C., Rodriguez-Flores, R., Virú-Vasquez, P., & Pilco-Nuñez, A. (2024). Bibliometric Analysis of Global Publications on Management, Trends, Energy, and the Innovation Impact of Green Hydrogen Production. *Sustainability*, *16*(24), 11048. https://doi.org/10.3390/su162411048

Roucham, B., & Zaghdoud, O. (2025). Mapping Green Hydrogen and Renewable Energy Research in Extended BRICS (Brazil, Russia, India, China, South Africa and Others): A Bibliometric Approach with a Future Agenda. *Hydrogen*, *6*(2), 33. https://doi.org/10.3390/hydrogen6020033

Terlouw, T., Rosa, L., Bauer, C., & McKenna, R. (2024). Future hydrogen economies imply environmental trade-offs and a supply-demand mismatch. *Nature Communications*, *15*(1), 7043. https://doi.org/10.1038/s41467-024-51251-7

Turner, J. A. (2004). Sustainable Hydrogen Production. *Science*, *305*(5686), 972–974. https://doi.org/10.1126/science.1103197

Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Yang, Y., Zhao, C., Wang, Z., Fan, X., & Yan, C. (2024). Synergistic effects of N-doping and mesoporous structures in block copolymer-derived three-dimensionally ordered mesoporous carbon for PEMFC. *International Journal of Hydrogen Energy*, *51*, 747–757. https://doi.org/10.1016/j.ijhydene.2023.10.197

References

Journals Articles

- Ben Jemaa, R., Mansouri, R., Boukholda, I., & Bellagi, A. (2017). Energy and exergy investigation of R1234ze as R134a replacement in vapor compression chillers. International Journal of Hydrogen Energy, 42(17), 12877–12887. https://doi.org/10.1016/j.ijhydene.2016.12.010
- Chu, S., & Majumdar, A. (2012). Opportunities and challenges for a sustainable energy future. Nature, 488(7411), 294–303. https://doi.org/10.1038/nature11475
- Jeje, S. O., Marazani, T., Obiko, J. O., & Shongwe, M. B. (2024). Advancing the hydrogen production economy: A comprehensive review of technologies, sustainability, and future prospects. International Journal of Hydrogen Energy, 78, 642–661. https://doi.org/10.1016/j.ijhydene.2024.06.344
- Kar, S. K., Harichandan, S., & Roy, B. (2022a). Bibliometric analysis of the research on hydrogen economy: An analysis of current findings and roadmap ahead. International Journal of Hydrogen Energy, 47(20), 10803–10824. https://doi.org/10.1016/j.ijhydene.2022.01.137
- Khttps://doi.org/10.1016/j.ijhydene.2022.01.137
- Osman, S. H., Mat Yatim, N. S., Jehan Elham, O. S., Shaari, N., & Zakaria, Z. (2025). Three decades of hydrogen energy research: A bibliometric analysis on the evolution of green hydrogen technologies. Sustainable Energy & Fuels, 9(12), 3182–3202. https://doi.org/10.1039/D5SE00254K
- Rodríguez-Aburto, C., Poma-García, J., Montaño-Pisfil, J., Morcillo-Valdivia, P., Oyanguren-Ramirez, F., Santos-Mejia, C., Rodriguez-Flores, R., Virú-Vasquez, P., & Pilco-Nuñez, A. (2024). Bibliometric Analysis of Global Publications on Management, Trends, Energy, and the Innovation Impact of Green Hydrogen Production. Sustainability, 16(24), 11048. https://doi.org/10.3390/su162411048
- Roucham, B., & Zaghdoud, O. (2025). Mapping Green Hydrogen and Renewable Energy Research in Extended BRICS (Brazil, Russia, India, China, South Africa and Others): A Bibliometric Approach with a Future Agenda. Hydrogen, 6(2), 33. https://doi.org/10.3390/hydrogen6020033
- Terlouw, T., Rosa, L., Bauer, C., & McKenna, R. (2024). Future hydrogen economies imply environmental trade-offs and a supply-demand mismatch. Nature Communications, 15(1), 7043. https://doi.org/10.1038/s41467-024-51251-7

- Turner, J. A. (2004). Sustainable Hydrogen Production. Science, 305(5686), 972–974. https://doi.org/10.1126/science.1103197
- Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3
- Yang, Y., Zhao, C., Wang, Z., Fan, X., & Yan, C. (2024). Synergistic effects of N-doping and mesoporous structures in block copolymer-derived three-dimensionally ordered mesoporous carbon for PEMFC. International Journal of Hydrogen Energy, 51, 747–757. https://doi.org/10.1016/j.ijhydene.2023.10.197

Books & Reports

- Hydrogen production – Global Hydrogen Review 2024 – Analysis. (2024). IEA. https://www.iea.org/reports/global-hydrogen-review-2024/hydrogen-production
- International Energy Agency. (2019). The Future of Hydrogen: Seizing today's opportunities. OECD. https://doi.org/10.1787/1e0514c4-en