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Sustainable green hydrogen production with emphasis on techno economic assessment and methodological gaps

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Systematic Review

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Abstract

The escalating global demand for clean energy has intensified focus on green hydrogen as a sustainable alternative to fossil fuels. This research conducts a systematic literature review complemented by a comprehensive bibliometric analysis using VOSviewer to map research trends and collaborations. The study emphasizes techno-economic assessment through indicators like NPV, IRR, and LCOH. Following PRISMA protocols and the PICO framework via Parsifal software, we searched Scopus, Web of Science, and IEEE Xplore (2015–2025). After rigorous screening, 15 of 87 initially identified papers met all research criteria. Bibliometric analysis revealed key thematic clusters and international collaboration patterns, while the systematic review demonstrated substantial advances in quantitative methods for evaluating hydrogen viability, particularly in solar and wind applications. Nevertheless, critical gaps persist in methodological standardization and empirical validation across diverse geographical and economic contexts.

1. Introduction

The climate emergency and global pressure for a sustainable energy transition are redefining priorities in the energy sector. In this context, green hydrogen stands out as a promising alternative for decarbonizing emissions-intensive sectors such as industry and transportation [1, 2]. Unlike conventional methods based on natural gas or coal, its production does not emit carbon dioxide, making it central to carbon neutrality plans [3]. Despite its environmental potential, its economic viability still generates uncertainty. The high cost of electrolyzers, the variability of renewable energy prices, and the lack of consolidated infrastructure hinder its large-scale adoption [4, 5]. To address these challenges, studies have been evaluating the economic attractiveness of different technological arrangements through quantitative analyses, such as Monte Carlo simulations, sensitivity analyses, and economic indicators, including Net Present Value (NPV), Internal Rate of Return (IRR), and Levelized Cost of Hydrogen (LCOH) [6–8].

Despite advances, there is a lack of standardized criteria to indicate how methods have been applied and which results predominate in analyses. The diversity of techniques and the lack of standardization hinder comparisons and compromise consistent evidence-based policies [9]. Furthermore, research is concentrated in high-income countries, while developing regions remain unexplored [10, 11]. In this context, it is relevant to systematically review the literature on sustainable green hydrogen production, focusing on the application of economic tools in renewable systems. By organizing and evaluating methods, contexts, and findings, this study consolidates the state of the art and supports strategic decisions in clean energy.

However, a conventional systematic review, while effective for synthesizing specific findings, may not fully capture the broader intellectual structure and evolving trends of a rapidly developing field. To address this, our study employs a dual-method approach, combining a systematic review with a comprehensive bibliometric analysis. This mixed methodology allows us not only to consolidate the

techno-economic evidence but also to map the conceptual landscape, identify key research fronts, and visualize global collaboration networks. By doing so, we provide a more holistic understanding of how knowledge in green hydrogen techno-economics is organized, interconnected, and evolving, thereby revealing gaps and opportunities that might remain hidden in a traditional review.

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2. Methodological Procedures

This study adopted a mixed-method methodological approach, combining a Systematic Literature Review (SLR) with a Bibliometric Analysis. The aim was not only to qualitatively synthesize existing evidence on the techno-economic feasibility of green hydrogen but also to quantitatively map the intellectual structure and evolutionary trends of this research field. The entire process was conducted with the support of the Parsifal platform [12], which facilitates the management of the various stages of a systematic review, ensuring transparency and reproducibility. The guidelines proposed by Kitchenham[13] and Petersen et al.[14] were followed, encompassing the formulation of the research question, definition of eligibility criteria, execution of comprehensive searches, and data extraction and synthesis.

The central review question was structured according to the PICO protocol (Population, Intervention, Comparison, Outcomes) [15]. The Population of focus consisted of studies on green hydrogen production via electrolysis. The Intervention investigated was the application of economic analysis tools, such as Monte Carlo simulations, Net Present Value (NPV), Internal Rate of Return (IRR), and Levelized Cost of Hydrogen (LCOH). The Comparison contextualized these methods against conventional production approaches or purely deterministic analyses. Finally, the Outcomes of interest included metrics of economic feasibility and sustainability in systems powered by renewable energy sources.

To identify the relevant literature, a comprehensive search strategy was implemented across three prestigious bibliographic databases with extensive coverage in engineering and energy fields: Scopus, Web of Science, and IEEE Xplore [16]. The temporal scope was defined from 2015 to 2025, capturing the phase of accelerated development of green hydrogen technologies, and the search was restricted to documents published in English. The search string was carefully constructed from the PICO components and applied to the title, abstract, and keyword fields. The final search string used was: ("electrolysis systems" OR "green hydrogen" OR "renewable energy" OR "solar energy" OR "water electrolysis") AND ("Monte Carlo simulation" OR "economic analysis" OR "economic modeling" OR "solar photovoltaic energy" OR "stochastic evaluation" OR "wind energy") AND ("conventional hydrogen production" OR "deterministic analysis" OR "renewable energy sources") AND ("economic feasibility" OR "levelized cost of hydrogen (LCOH)" OR "production costs" OR "return on investment" OR "uncertainty reduction*").

The study selection process was conducted in two stages. First, titles and abstracts were screened against exclusion criteria (duplicates, non-relevance, grey literature, inaccessible full texts).

Subsequently, the full texts of the remaining articles were critically appraised for methodological quality using a specific instrument that scored studies from 0 to 9.0, with a minimum cutoff of 4.0 for inclusion. Data from the final selected studies were systematically extracted into a standardized matrix for qualitative synthesis.

To complement the systematic review and provide an objective, macro-level overview of the research field, a bibliometric analysis was performed using VOSviewer software (version 1.6.20) [17]. Bibliographic data from Scopus and Web of Science were utilized. VOSviewer was employed to create network maps based on keyword co-occurrence, where the size of nodes represents term frequency, the distance between nodes indicates the strength of their relationship, and distinct colored clusters reveal thematic associations. This technique allowed for the visualization of key research domains and emerging trends, thereby validating and enriching the findings from the systematic review.

3. Results and discussion

The initial identification stage yielded 1,120 papers: 377 from Scopus, 218 from Web of Science, and 525 from the IEEE Digital Library. Figure 1 shows the percentage distribution by database. After screening, including reading titles and abstracts and removing duplicates, 483 papers were selected: 280 from Scopus, 153 from Web of Science, and 50 from the IEEE Digital Library. The flowchart in Fig. 2 summarizes the steps of study identification, screening, eligibility, and inclusion.

Source: Authors.

In the eligibility phase, the papers were assessed according to previously defined quality criteria. As a result, 87 studies were approved and submitted to detailed qualitative analysis. Figure 3 shows the number of papers identified, screened, and eligible by the databases. Of these, 15 were considered relevant for the final synthesis because they directly addressed the techno-economic analysis of green hydrogen production, using methods such as Monte Carlo, NPV, IRR, and LCOH in solar and wind systems

Source: Authors.

Source: Authors.

In addition to the quantitative analysis of the selection process, we examined the temporal distribution of the papers in the final portfolio. Figure 4 highlights a significant increase in publications on techno-economic analysis of green hydrogen from 2021 onward, reflecting the growing academic and industrial interest driven by the urgency of the energy transition.

Source: Authors.

3.1. Portfolio

The portfolio section brings together the studies with the best qualitative evaluation, based on methodological criteria. After screening and applying inclusion, exclusion, and quality criteria, 15 papers were selected for their greatest relevance, methodological clarity, and applicability to the sustainable production of green hydrogen from renewable sources, such as solar and wind. Each paper was cataloged with authors, year, citation count, evaluation score, and a summary of key objectives and findings, enabling comparative analysis to identify patterns, trends, and gaps in the literature.

The selected studies present diverse approaches, from economic analyses with NPV, IRR, and LCOH to stochastic simulations, optimization algorithms, and regional case studies, highlighting the need for a multidimensional assessment of the viability of green hydrogen in different contexts. Thus, the portfolio serves as a structured core of scientific evidence that supports discussions, conclusions, and recommendations. Table 1 presents the main papers and their technical characteristics.

Table 1
– Articles that make up the systematic review portfolio.

Paper	Authors	Citation count	Score	Summary
Innovative Strategies for Combining Solar and Wind Energy with Green Hydrogen Systems	[18]	4	7.5	The paper discusses how the integration of wind and solar energy with green hydrogen technologies represents an innovative approach to achieving sustainable energy solutions.
Exploring the Feasibility of Green Hydrogen Production Using Wind Energy in India	[19]	5	6	This study evaluates five high-speed wind sites in India for green hydrogen production, analyzing the potential of wind resources using six different wind turbine models. A comprehensive techno-economic analysis was conducted to assess the feasibility of hydrogen production, considering factors such as annual energy production, hydrogen production, levelized cost of energy (LCOE), and levelized cost of hydrogen (LCOH).
Economic Viability Analysis of a Renewable Energy System for Green Hydrogen and Ammonia Production	[20]	8	7.5	This paper presents a methodology for assessing the long-term economic viability of renewable energy-based systems for the production of green hydrogen and ammonia. A key innovation of this approach is the incorporation of a predictive algorithm that optimizes system operation a day in advance, hourly, to maximize profit.
Green hydrogen production from wind energy in Far Eastern Federal District (FEFD), the Russian Federation	[21]	7	9	This study assessed the potential for developing wind-based green hydrogen energy in the Far Eastern Federal District (FEFD) of the Russian Federation. Empirical wind speed data were collected from 20 meteorological stations in four regions (Sakhalinskaya Oblast, Primorskiy Krai, Khabarovskiy Krai, and Amurskaya Oblast) of the FEFD. The Weibull distribution was used to predict the potential for green hydrogen production.
Techno-economic feasibility and regression analysis of green hydrogen production from solar and wind energy in Türkiye	[22]	10	9	This study presents a new approach to assess the economic feasibility of green hydrogen production in Turkey, powered by renewable energy sources such as wind and photovoltaic systems, with cost calculations performed through regression analysis.
RES-electrolyser coupling within TRIERES hydrogen valley – A flexible	[8]	2	8	This paper seeks to delve deeper into this topic by developing a dynamic technical-economic analysis tool capable of flexibly evaluating the optimal

Paper	Authors	Citation count	Score	Summary
technoeconomic assessment tool				configuration of alkaline electrolysis (AEL) coupled with RES in a specific region or hub. The focus is on achieving cost-effectiveness, efficiency, and sustainable green hydrogen production.
Techno economic model to analyze the prospects of hydrogen production in Colombia	[5]	19	9	In this study, combinations of three types of renewable energy sources (offshore wind, onshore wind, and solar PV) along with PEMWE and AWE were thoroughly investigated to determine the technical and economic feasibility of green hydrogen production. In this study, realistic calculations were made using meteorological information from databases such as NASA and IDEAM, with measurements over a one-year time window. Based on this, the estimated electrical energy produced was calculated using a mathematical model.
Optimum sizing of hybrid renewable power systems for on-site hydrogen refuelling stations: Case studies from Türkiye and Spain	[4]	37	9	This study provides a techno-economic analysis of an on-site hydrogen refueling station powered by a hybrid renewable energy generation system using HOMER software in Niğde, Turkey, and Zaragoza, Spain. Three different energy system scenarios were evaluated to refuel 24 vehicles per day for each region throughout the year. The analysis results showed that the most optimized system architecture for Niğde was a power generation system with a levelized cost of hydrogen (LCOH) of $6.15/kg and a net present cost (NPC) of $6,832,393.
A Techno-Economic Feasibility Study of Electricity and Hydrogen Production in Hybrid Solar-Wind Energy Park. The Case Study of Tunisian Sahel	[23]	5	8	This paper provides a comprehensive analysis of the potential for integrating renewable energy sources to meet the growing demand for electricity and hydrogen in the Tunisian Sahel region, with a particular focus on solar and wind power. The feasibility of installing a hybrid solar and wind power system capable of producing both electricity and hydrogen is assessed.
Hydrogen Production Methods Based on Solar and Wind Energy: A Review	[24]	40	7.5	This study compares different hydrogen production methods based on PV and WG systems. A comparative study of different electrolyzer types is also presented and discussed. Lastly, an economic assessment of green hydrogen production is given
Recent developments in the production of	[2]	23	8.5	The main objective of this paper is to comprehensively review the advantages

Paper	Authors	Citation count	Score	Summary
hydrogen: Efficiency comparison of different techniques, economic dimensions, challenges and environmental impacts				and disadvantages of various H2 production techniques. Furthermore, the economic dimensions of each technique, along with the role of nanotechnology in H2 production, will be reviewed in this paper.
Sustainable hydrogen production: Technological advancements and economic analysis	[1]	20	9	The current study therefore addresses these gaps to effectively direct future research toward improving H2 production techniques. Many conventional methods contribute to large greenhouse gas footprints, with high production costs and low efficiency. Steam methane reforming and coal gasification dominate the H2 supply side due to their low production costs (< US$3.50/kg).
Analysis of the economic and technological viability of producing green hydrogen with renewable energy sources in a variety of climates to reduce CO2 emissions: A case study in Egypt	[25]	12	9	There are many promising energy technologies, but green hydrogen stands out as a pioneer. Green hydrogen capacity was evaluated in this paper as a potential new means of storing Egypt's renewable electricity and fuel.
Techno-Economic Analysis of Territorial Case Studies for the Integrationof Biorefineries and Green Hydrogen	[26]	7	9	Through techno-economic assessments, this paper analyzes four local case studies that integrate bio-based processes with green hydrogen produced by electrolysis using renewable energy sources. An analysis of the use of WebGIS tools (i.e., the IEA Bioenergy Biorefinery Atlas) to identify existing bio-refineries requiring hydrogen in relation to territories with potential green hydrogen availability has never been conducted before.
Techno-economic and environmental assessment of green hydrogen andammonia production from solar and wind energy in the republic ofDjibouti: A geospatial modeling approach	[27]	9	9	This study conducts a comprehensive economic and technical analysis to assess the feasibility of producing green hydrogen and green ammonia using renewable energy sources in the Republic of Djibouti. We explore the economic competitiveness of utilizing wind and solar energy for sustainable energy production through several measures, including levelized cost of energy (LCOE), hydrogen (LCOH), and ammonia (LCOA).

Source: Authors.

3.2. Economic viability of green hydrogen production projects based on solar and wind energy

An analysis of the 15 papers reveals a growing trend in studies on the economic viability of green hydrogen combined with renewable sources, especially solar photovoltaic and wind power. Ref. [20] highlight that hybrid projects increase energy security in regions with pronounced seasonality, while [22] show that this combination significantly reduces LCOH and mitigates intermittent risks.

Using Monte Carlo simulations and discounted cash flow analysis (NPV and IRR), the authors identified scenarios of uncertainty and identified electrolyzer CAPEX and efficiency as critical factors for profitability. Renewable electricity costs, tax incentives, and public policies were also decisive. Thus, economic viability depends on variables such as cost of capital, capacity factor, location, and efficiency, reinforcing the need for robust financial models that consider uncertainties and operational fluctuations over time

- **3.3. Integration of photovoltaic and wind energy affects the cost-benefit ratio of hydrogen production by electrolysis**

The integration of photovoltaic and wind systems is critical to optimizing the cost-effectiveness of green hydrogen production through electrolysis. Studies by[4] and[21] show that the combined use of these sources mitigates intermittency, generates a more stable and continuous curve, allows for uninterrupted operation of electrolyzers, increases the capacity factor, and reduces operating costs and LCOH.

Simulations in regions with different climate profiles indicate that efficiency depends on the synchronization between supply and demand and the storage configuration. In areas with greater solar seasonality, wind energy acts as a complementary source, ensuring supply during periods of low sunlight. These results demonstrate that proper sizing and energy management are essential for economic returns, in addition to reducing dependence on the electricity grid and increasing the autonomy of decentralized systems, especially in rural and remote areas.

3.4. Main uncertainties affecting the economic viability of green hydrogen

The main uncertainties identified relate to the variability of renewable resources, regulatory instability, hydrogen price volatility, and technological limitations of electrolyzers. These factors affect indicators such as LCOH and compromise the predictability of financial returns. Studies such as [5] and [2] highlight the need for robust tools, such as Monte Carlo simulations, to quantify risks and analyze key variables.

The unpredictability of electrolyzer technological advancements creates uncertainty about efficiency and future costs, especially in long-term projects. Furthermore, uncertain carbon pricing makes it difficult to

estimate carbon credit revenues. To mitigate these risks, some authors propose integrating scenario analyses and public policy simulations, assessing the impact of subsidies, tariffs, and tax incentives on the green hydrogen economy.

3.5. Monte Carlo simulation and its influence on investment decisions in green hydrogen production infrastructure

Monte Carlo simulation has emerged as a widely used approach in portfolio studies, especially in the financial evaluation of green hydrogen projects under conditions of uncertainty. Refs. [1] and [26] demonstrate its effectiveness in modeling complex probabilistic scenarios, enabling more realistic analyses of returns on investment (ROI) and economic indicators such as Net Present Value (NPV) and Levelized Cost of Hydrogen (LCOH).

Its main advantage is its ability to incorporate variables and statistical distributions, such as electricity prices, electrolyzer CAPEX, efficiency, and discount rates, generating thousands of results and assessing project sensitivity to uncertainty. Ref. [1] showed that different distributions (triangular, normal, lognormal) can significantly alter the results. Combined with scenario analysis, the technique helps identify critical points, strengthens risk mitigation strategies, and provides technical support for prioritizing investments in different regulatory and market contexts. This makes decision-making in green hydrogen projects more informed, transparent, and less exposed to financial risks.

3.6. Stochastic and economic evaluation of renewable hydrogen projects

Stochastic and economic assessments stand out as essential strategies for dealing with the variability of parameters that influence renewable hydrogen production. Tools such as Monte Carlo simulation, dynamic LCOH, and scenario analysis allow for the estimation of profitability ranges under different market, climate, and operating conditions, offering decision-makers a probabilistic view of risks and returns.

Optimization and predictive modeling algorithms, such as those applied by [20], expand the ability to predict extreme situations, such as abrupt variations in electricity costs or electrolyzer efficiency, favoring long-term strategic planning. This approach is crucial in high-CAPEX projects with long amortization horizons, where poor decisions can compromise economic goals. Thus, technoeconomic analysis should be seen not as a static process, based on average values, but as an iterative and adaptive method, incorporating uncertainties, feedback from real data, and multiple decision paths, with a focus on maximizing gains and mitigating risks.

3.7. A Comparative Bibliometric Analysis: Divergent Research Fronts in Scopus and Web of Science

A comparative bibliometric analysis of author keywords from the Web of Science (WoS) and Scopus databases reveals not just nuances, but significantly divergent research fronts within the green hydrogen

domain. This divergence underscores the complementary nature of these major databases and highlights the multifaceted character of the field. The intellectual structure mapped from the Web of Science database (Fig. 5) presents a paradigm strongly anchored in energy economics and systemic viability. The centrality of "levelized cost of hydrogen (LCOH)" and "techno-economic analysis," tightly coupled with "renewable energy sources," "solar energy," and "wind energy," delineates a research community focused on establishing the foundational economic and technical prerequisites for green hydrogen. This corpus is predominantly concerned with answering the core question: Is large-scale green hydrogen production feasible and financially viable? The network suggests a focus on modeling, simulation, and high-level integration with renewable energy systems, forming the essential theoretical and macroeconomic groundwork for the hydrogen economy.

In stark contrast, the research landscape emerging from the Scopus database (Fig. 6) shifts the focus from foundational viability to applied engineering and sectoral integration. Here, the keyword network reveals a research stream deeply engaged with practical implementation. The presence of specific industrial terms like "pellettizing" and "quality requirements" indicates a concern with hydrogen storage, transport, and standardization—critical challenges for creating a marketable commodity. Similarly, terms such as "bollers" (boilers) and "vehicles" point to concrete research on hydrogen utilization in end-use sectors like industrial heat and transportation. Most notably, the direct link to "coal mining" unveils a targeted research front exploring the role of green hydrogen in the just transition of fossil-fuel-dependent regions and industries, a theme less prominent in the WoS corpus. This stark divergence is not a mere artifact of indexing but reflects the distinct scope and coverage of each database. Web of Science often captures a core of high-impact, theoretically-driven journals, while Scopus's broader coverage includes more conference proceedings and applied engineering literature. Therefore, this comparison validates that relying on a single database would yield a fragmented understanding. The WoS-based view provides the economic and strategic rationale, while the Scopus-based view details the technical and operational pathways for implementation. Together, they offer a holistic view of green hydrogen research, spanning from macroeconomic modeling to granular engineering challenges, affirming the field's maturation from theoretical concept to an emerging industrial reality.

Source: Authors.

Source: Authors.

3.8. Contrasting Intellectual Foundations: A Comparative Reference Co-citation Analysis of Web of Science and Scopus

The comparison of reference co-citation networks between Scopus and Web of Science (WoS) reveals fundamental differences in the intellectual foundations underpinning green hydrogen research across these databases.

The Web of Science network (Fig. 7) is characterized by high-impact seminal articles published in renowned international journals (e.g., Nature Energy, International Journal of Hydrogen Energy). Authors such as Schmidt et al. (2017) and Buttler & Spliethoff (2018) represent foundational research in economic modeling and technology assessment that has become theoretical pillars for the field, forming a centralized and consolidated "intellectual glue."

In contrast, the Scopus co-citation network (Fig. 8) reveals a notably more fragmented, applied, and regionally diverse intellectual base. The presence of authors like Kaidellis, J.K. (focusing on "maximum wind power" and "energy balance") and the citation of works on hybrid systems (e.g., Erdinc, Ozan, "optimum design") indicate a strong influence of research aimed at technical optimization and renewable systems integration at local or regional scales. The marked presence of technical reports (e.g., IEA's "Global Hydrogen Review 2023") and even highly specific sectoral case studies (e.g., "Poultry Industry in Lebanon") corroborates the applied, less theoretical nature of the Scopus corpus. This database appears to capture the field's "practical glue" – the studies that applied researchers and engineers use to solve concrete integration and feasibility problems. This divergence is crucial. It demonstrates that the communities publishing in and indexed by each database operate in distinct literature ecosystems. WoS reflects a global academic dialogue centered on models and policies, while Scopus captures an additional layer of applied research, technological development, and regional case studies that are essential for real-world implementation but often have lower international visibility. Therefore, this analysis validates that using both databases was imperative to capture not only the theoretical foundations of the field but also its operational and contextual pulse.

Figure 7. Reference co-citation network of the foundational literature in green hydrogen techno-economic research WoS.

Source: Authors.

Source: Authors.

3.9. Mapping Global Collaboration: A Comparative Analysis of Country Co-Authorship Networks

A comparative analysis of country co-authorship networks from Web of Science (WoS) and Scopus reveals significant differences in the geographical representation of green hydrogen research, highlighting the importance of a multi-database approach.

The Web of Science network (Fig. 9) presented a focused yet strategically significant map. It highlighted activity in technological leaders like Japan and resource-rich nations such as Saudi Arabia, Egypt, Nigeria, and Sudan. This suggested a WoS corpus capturing high-impact, strategic research alliances and studies in regions with high renewable potential. In contrast, the Scopus network (Fig. 10) unveils a dramatically more expansive, diverse, and granular global research landscape. The Scopus map confirms the activity of major players identified in WoS, such as China, the United States, India, Japan,

and Saudi Arabia. However, it also brings to light a much wider array of actively contributing countries. Notably, it shows a strong presence of European nations (France, Spain, Italy, Germany, Norway, Poland, Turkey) and reveals significant research activity in Latin America (Brazil, Colombia, Mexico), and across Southeast Asia (Malaysia, Vietnam, Thailand). Furthermore, it captures contributions from numerous African nations (South Africa, Cameroon, Ethiopia) beyond those seen in WoS.

This stark contrast demonstrates that Scopus, with its broader coverage of conference proceedings and international journals, captures a more comprehensive picture of global research efforts. It effectively maps the "long tail" of green hydrogen research, highlighting emerging and regional research hubs that are less visible in the WoS corpus. This analysis provides robust empirical evidence that reliance on a single database would lead to an incomplete and potentially biased understanding of the global research geography, significantly underrepresenting the contributions from Latin America, Southeast Asia, and parts of Europe and Africa. The true global research landscape on green hydrogen is far more wide-reaching and interconnected than what appears in any single database.

Source: Authors.

Source: Authors.

3.10. Research Gaps and Implications

Based on the comprehensive bibliometric and systematic analyses conducted, this study identifies several critical research gaps and their implications for the field of green hydrogen. The systematic review revealed a significant shortage of long-term empirical studies monitoring the real-world performance of green hydrogen production systems, with a predominant reliance on theoretical models and simulations over actual operational data. Furthermore, the research landscape demonstrates a notable lack of interdisciplinary approaches that effectively integrate technical, economic, social, and environmental dimensions into a cohesive analytical framework.

Geographically, substantial disparities in research focus were identified. While the bibliometric analysis confirmed research activity in some Global South nations, there remains a pronounced underrepresentation of applied studies from regions with high renewable potential, particularly Latin America and Africa. Theoretically, the field lacks a robust conceptual framework capable of unifying the treatment of uncertainty, risk, and technological innovation within techno-economic assessment models. This points to the necessity of developing adaptive, geospatial evaluation frameworks that can accommodate dynamic market and technological conditions.

In practical terms, the scarcity of empirical data constrains the ability of policymakers, investors, and project managers to make fully informed decisions regarding project viability. Although modeling and simulations provide valuable insights, they cannot substitute for field evidence in validating economic and operational assumptions. To address these gaps, future research should prioritize applied case studies utilizing mixed-methods approaches, and investigate underexplored contexts such as small

islands, arid zones, and regions with limited energy access. These studies should integrate detailed environmental impact assessments and broader sustainability indicators.

A primary limitation of this review lies in its focus on English-language publications indexed in three major databases (Scopus, Web of Science, IEEE Xplore) within the 2015–2025 timeframe, which may have omitted relevant contributions in other languages or from earlier periods. Nonetheless, these constraints further underscore the need for more inclusive and comprehensive research frameworks in future studies.

4. Final Considerations

This study sought to synthesize the evidence regarding the economic viability of green hydrogen production from renewable sources, with a specific focus on the application of key financial and risk assessment methodologies such as Monte Carlo simulation, Net Present Value (NPV), Internal Rate of Return (IRR), and Levelized Cost of Hydrogen (LCOH). Through a systematic literature review complemented by a bibliometric analysis, this research has consolidated the current state of knowledge on the techno-economic aspects of these systems and the methodological tools employed in their evaluation.

The findings confirm that the economic viability of green hydrogen is highly sensitive to a range of factors. Results from stochastic analyses, particularly Monte Carlo simulations, consistently highlight that capital expenditures (CAPEX) for electrolyzers and renewable energy infrastructure, alongside macroeconomic variables such as interest rates and hydrogen selling prices, remain significant challenges. These elements, characterized by their volatility and uncertainty, are pivotal in determining project feasibility. However, the application of stochastic methods proves crucial in identifying specific scenarios and risk thresholds under which production can become economically viable, thereby providing a more robust foundation for investment decisions.

The application of bibliometric techniques revealed distinct intellectual foundations and collaboration patterns between major databases, demonstrating that a multi-database approach is critical to avoid a fragmented understanding of the field. This dual-methodological approach not only synthesized findings but also mapped the very structure of the research landscape, offering valuable insights for identifying potential collaborators and emerging niches.

Despite considerable progress in the field, this review underscores persistent and critical gaps. A primary concern is the lack of standardization in economic evaluation methodologies, which hinders direct comparability across studies. Furthermore, there is a pronounced need for more research tailored to the contexts of developing countries, where structural conditions, resource endowments, and financing landscapes differ substantially from high-income scenarios. To address these challenges and advance the field, it is recommended to foster more integrated analytical frameworks that combine advanced stochastic modelling with deeper financial and geospatial analysis. Concurrently, efforts must be made to strengthen open-access and updated databases, enhancing the reproducibility of studies and

providing a more reliable evidence base. Such initiatives are vital for informing the formulation of consistent and effective energy policies, ultimately accelerating the transition to and scaling up of sustainable green hydrogen production

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Author Contributions

Virgilio Juma Ali: Conceptualization, methodology, systematic review design, data curation, formal analysis, visualization, writing – original draft.

Thaina Neri Rodrigues Da Silva: Methodological support, validation, writing – review & editing.

Arsenio Mario Caetano: Supervision, project administration, writing – review & editing.

Competing Interests

The authors declare that they have no competing financial or non-financial interests.

Ethics Declaration

Ethics declaration: not applicable.

This study is based exclusively on previously published literature and does not involve human participants, animals, or biological material.

Consent to Participate

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Data Availability

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Figures

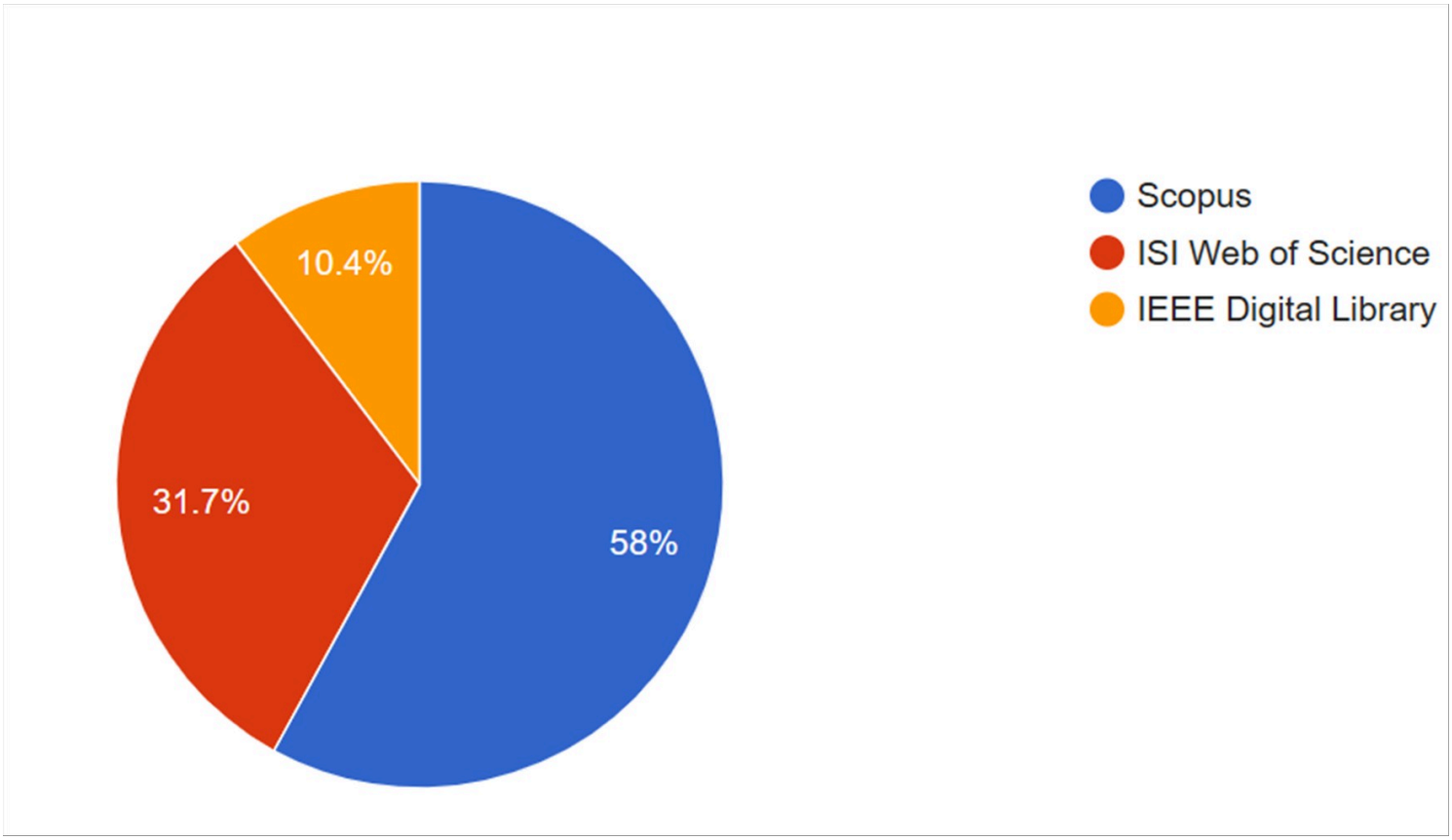


Figure 1

Percentage distribution of papers identified in the systematic review by database.

Source: Authors.

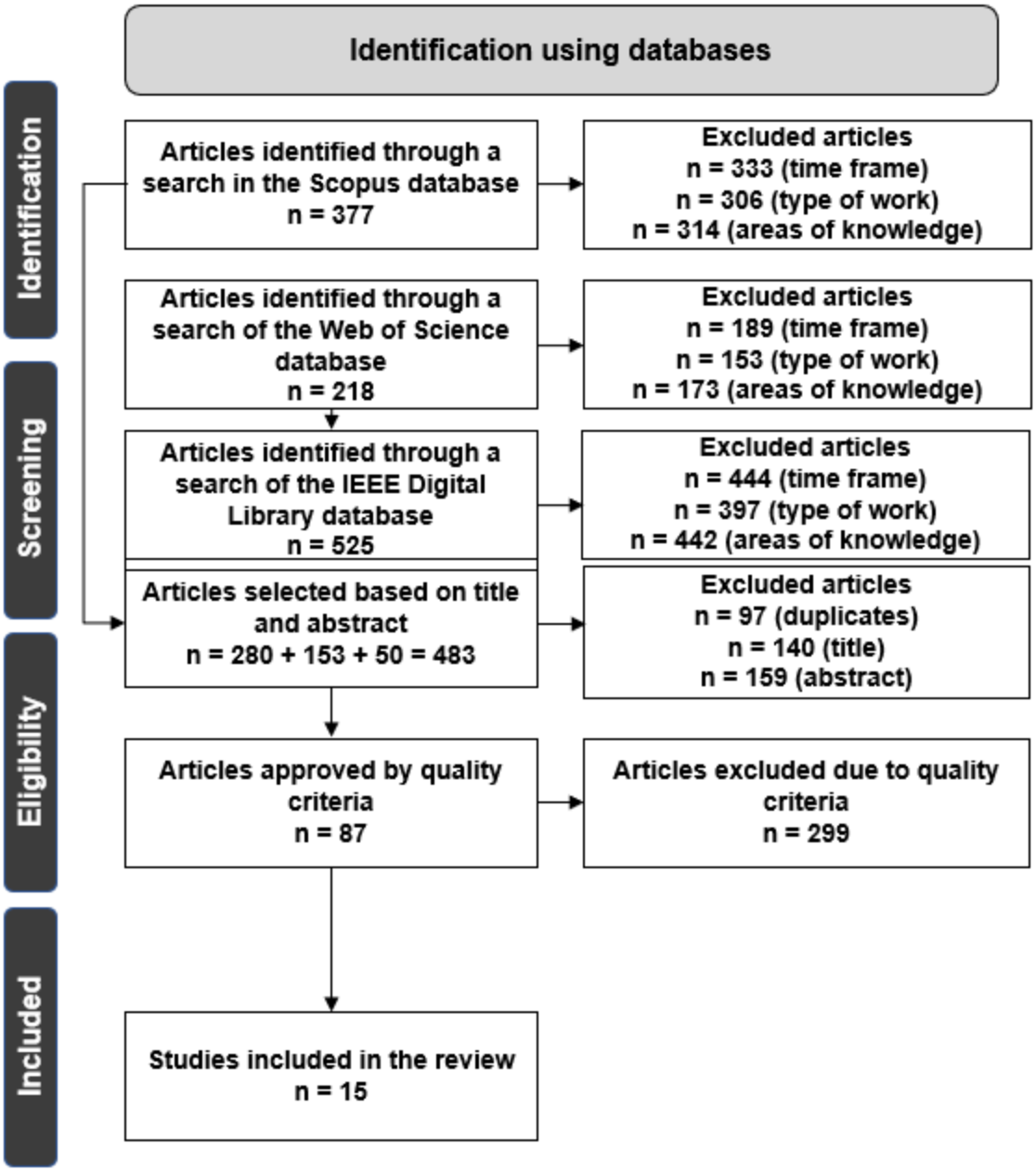


Figure 2

Flowchart of the steps for identification, screening, eligibility, and inclusion of studies.

Source: Authors.

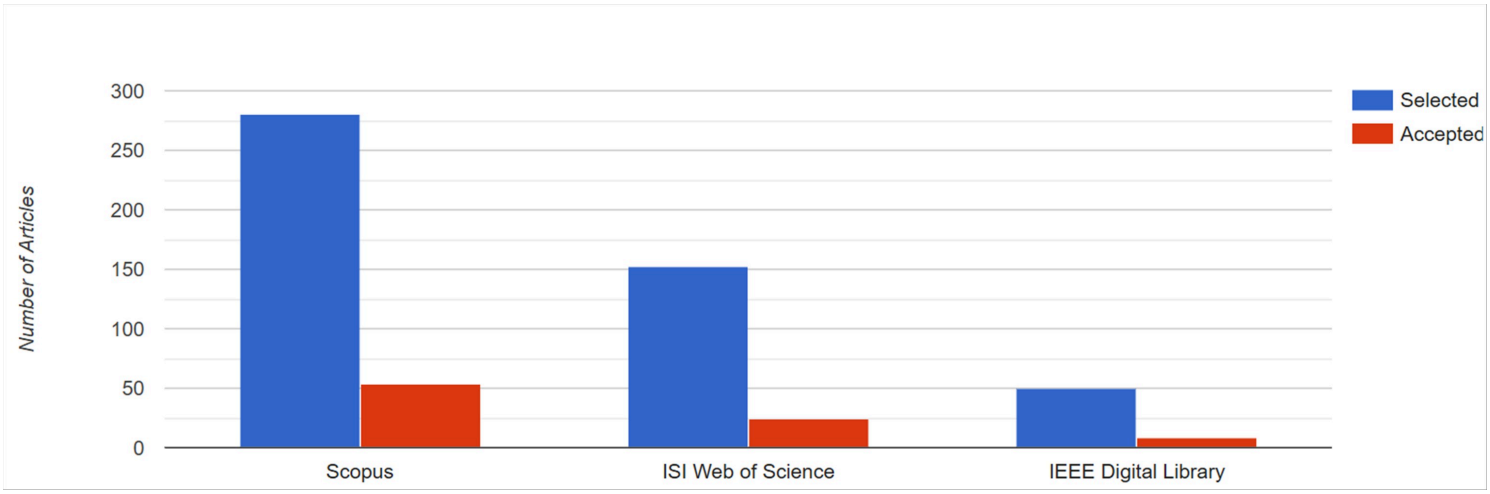


Figure 3

Number of papers per database in the identification stages, selected in the screening, and eligible for qualitative analysis.

Source: Authors.

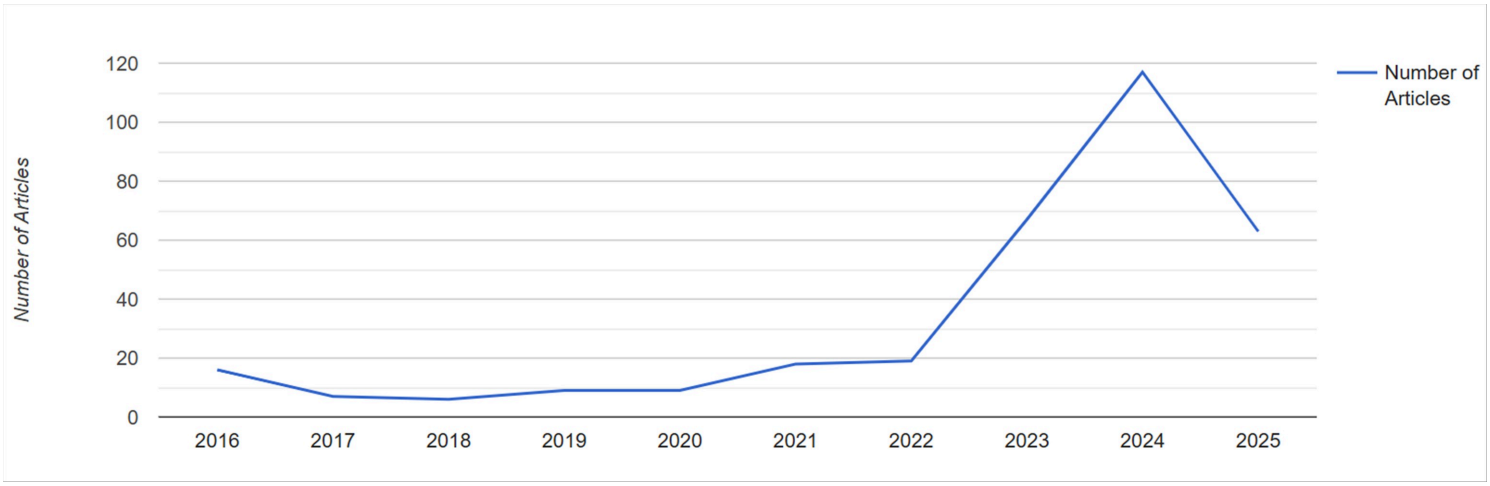


Figure 4

Temporal distribution of papers selected in the systematic review portfolio (2016-2025).

Source: Authors.

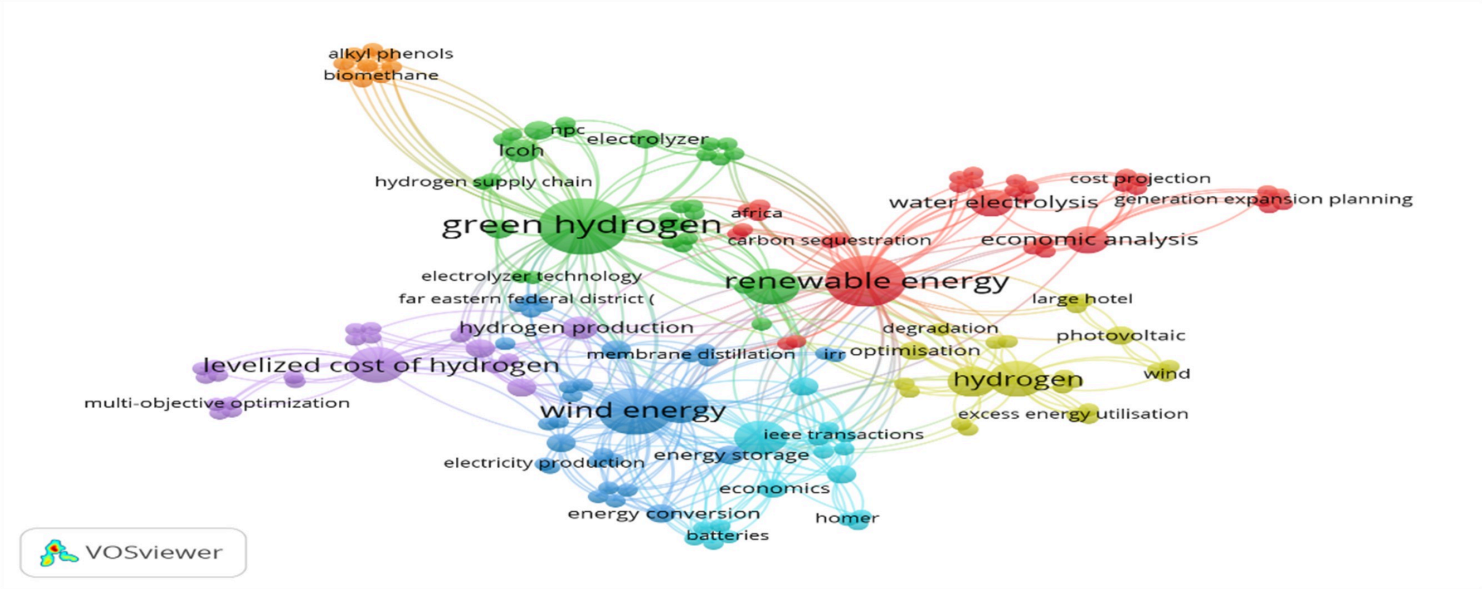


Figure 5

Author keyword co-occurrence network map of green hydrogen techno-economic research WoS.

Source: Authors.

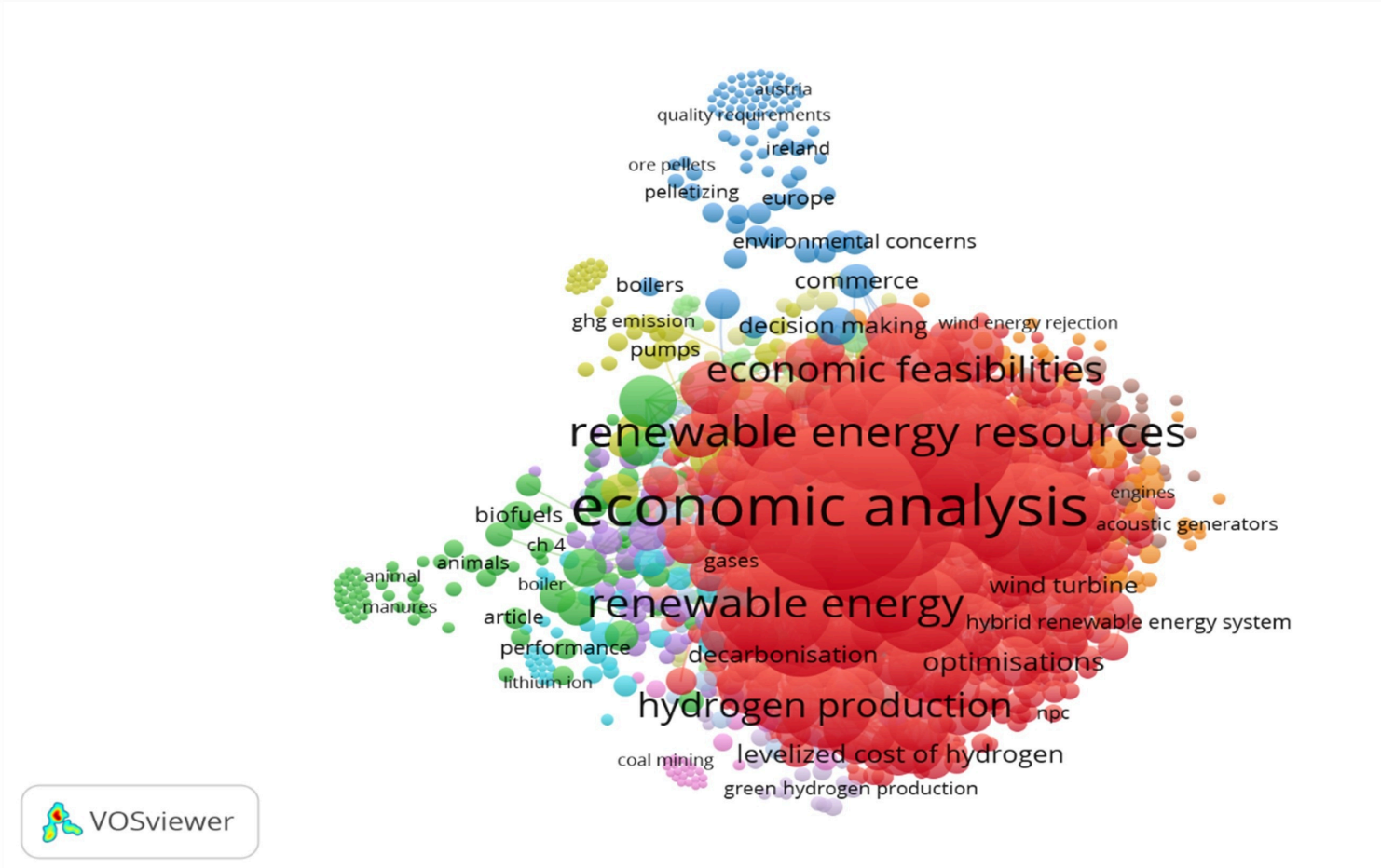


Figure 6

Author keyword co-occurrence network map of green hydrogen research Scopus.

Source: Authors.

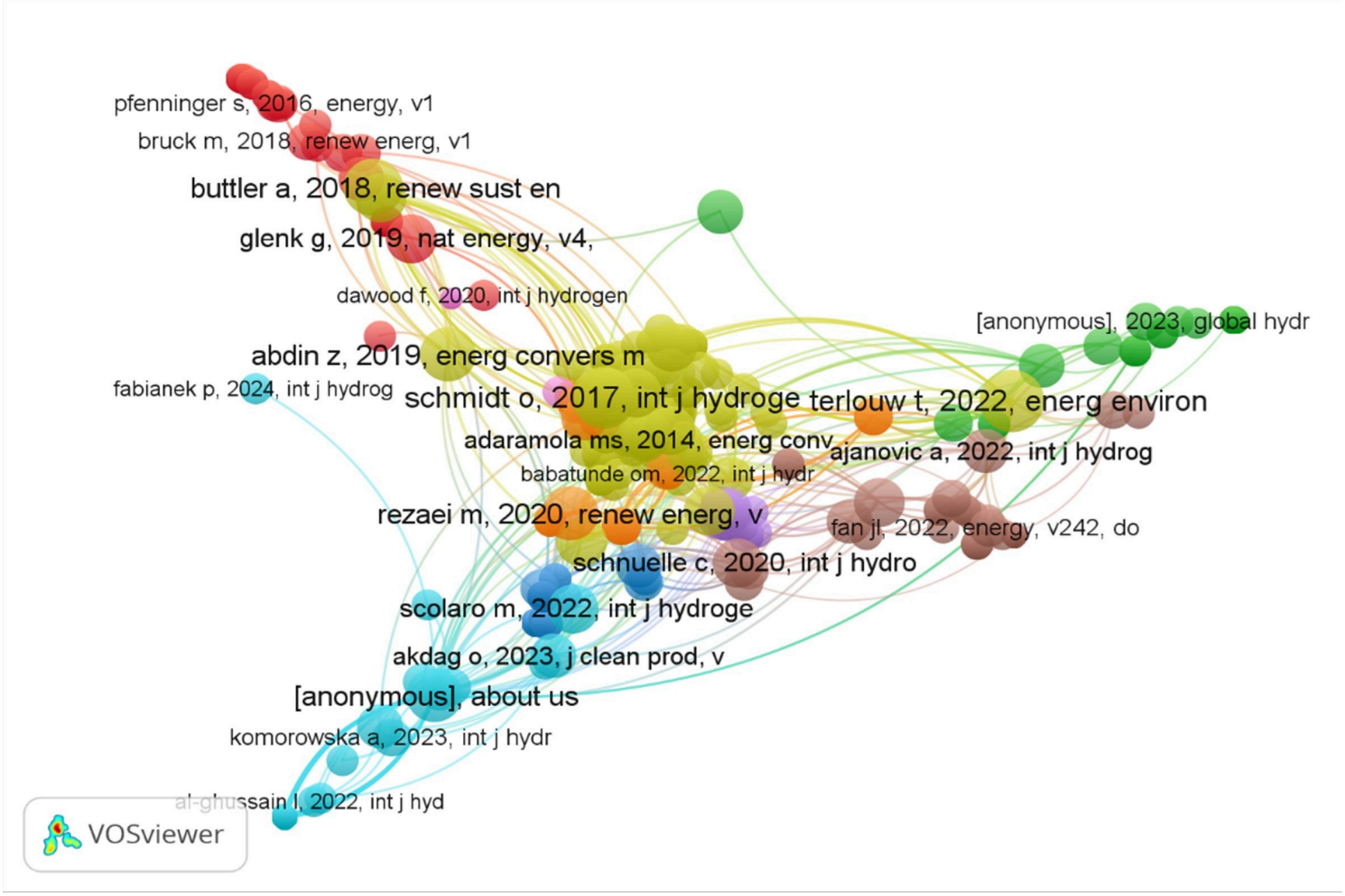


Figure 7

Reference co-citation network of the foundational literature in green hydrogen techno-economic research WoS.

Source: Authors.

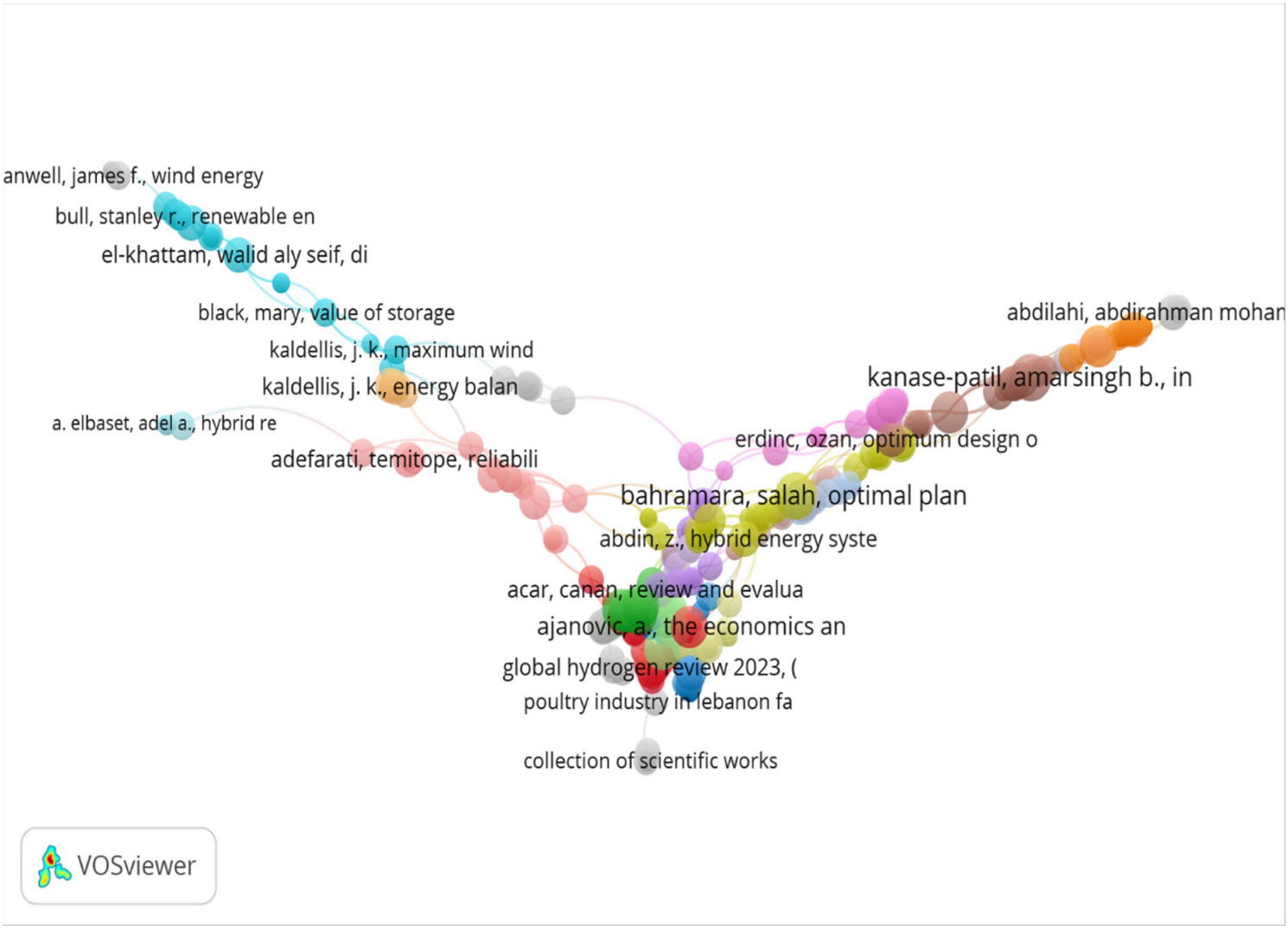


Figure 8

Reference co-citation network of the foundational literature in green hydrogen techno-economic research Scopus.

Source: Authors.

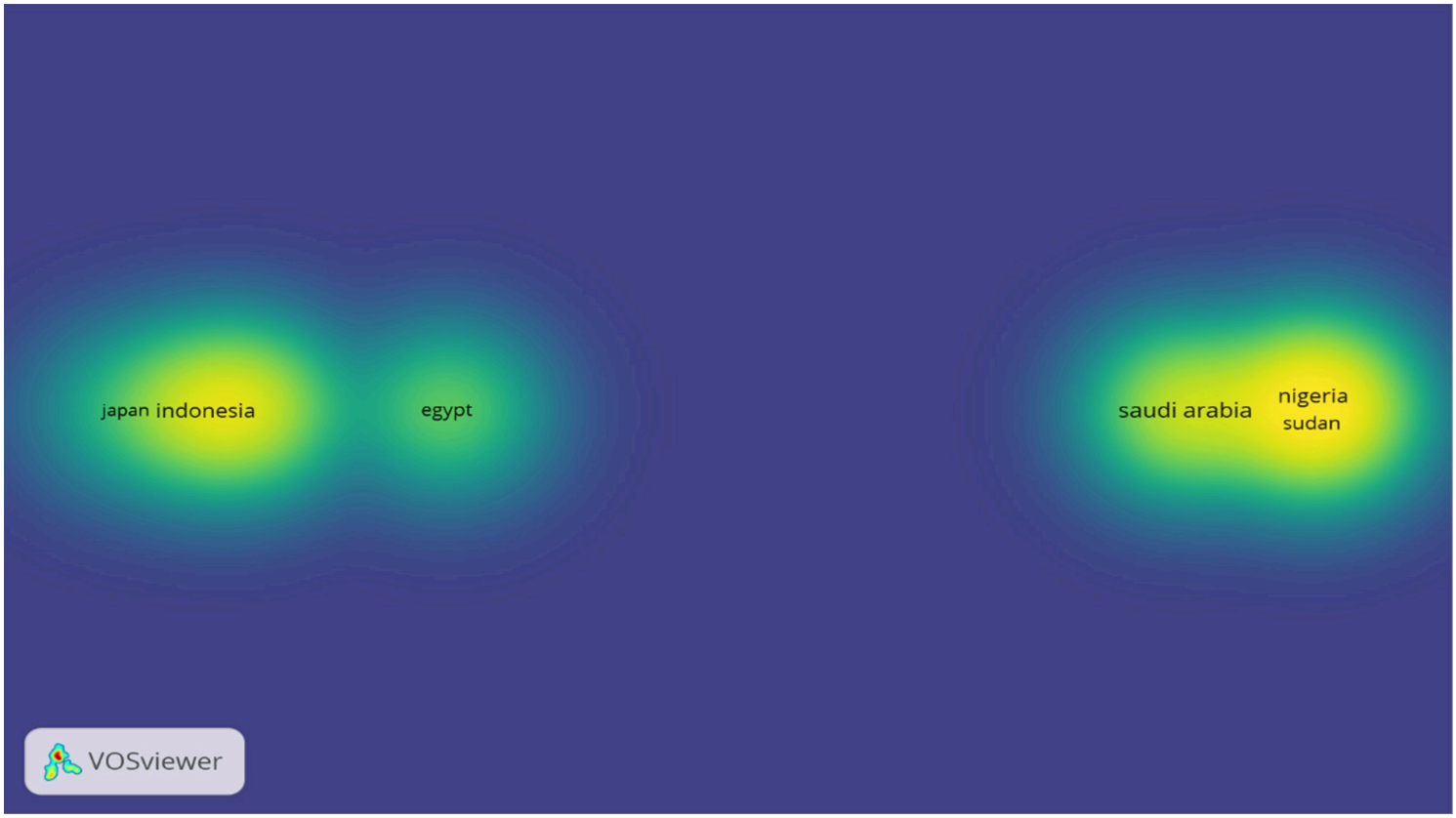


Figure 9

Country co-authorship network in green hydrogen research (Web of Science).

Source: Authors.

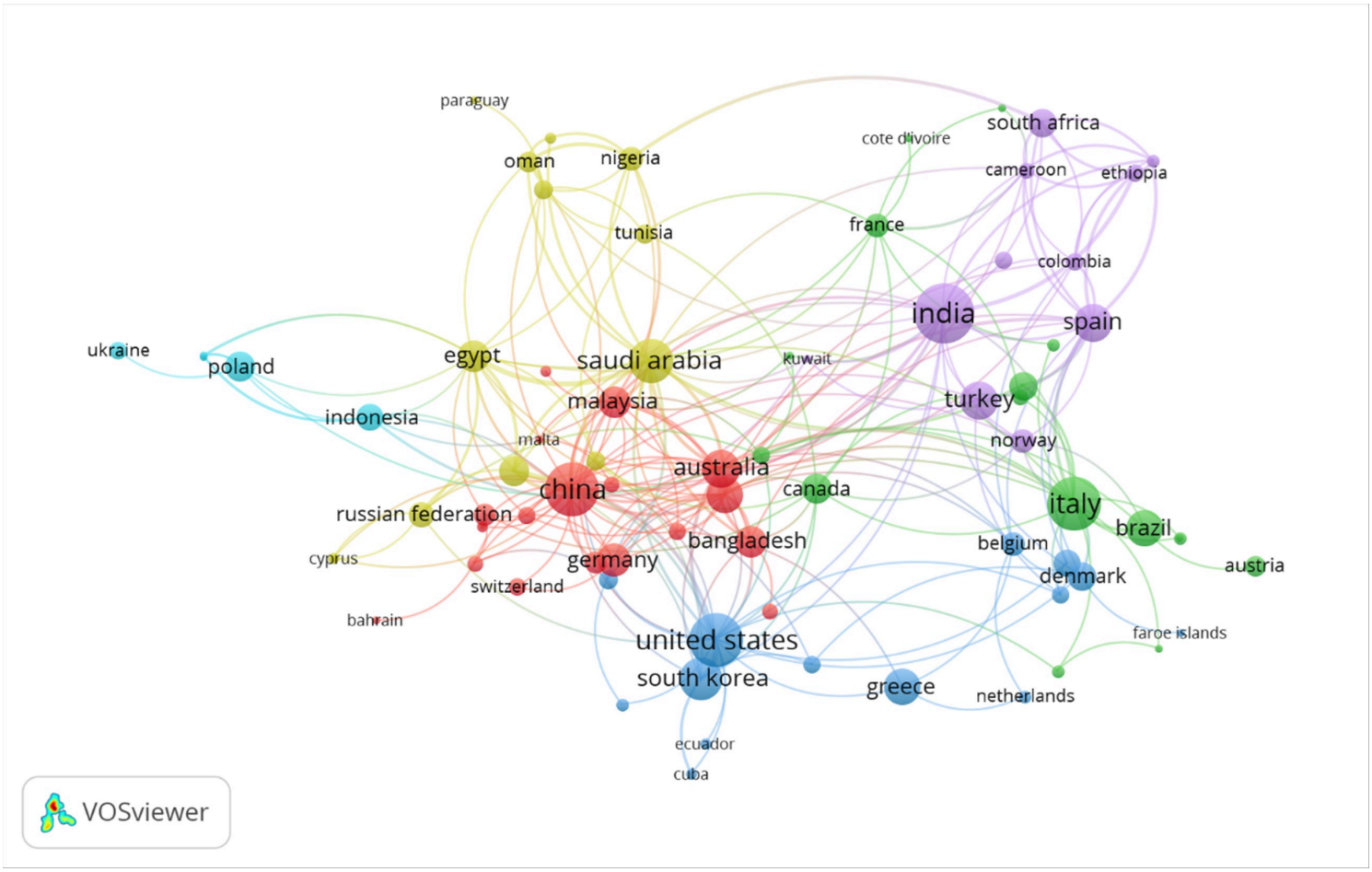


Figure 10

Country co-authorship network in green hydrogen research (Scopus).

Source: Authors.