Scaling Green Hydrogen: A Critical Review of Techno-Economic and Logistical Bottlenecks

Ashulekha Gupta[1], Anurag Shrivastava[1,2]
[1]Lincoln University, Malaysia,
[2]Department of Electronics & Communication and Computer Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamilnadu, India,
Email id: pdf.Ashulekha@lincoln.edu.my, anuragshri76@gmail.com

Abstract

Green hydrogen is considered a key enabler of the global energy transition, particularly for decarbonizing hard-to-abate sectors like heavy industry, shipping, and aviation. However, several barriers hinder its widespread adoption. In the Scopus database key words used "Green Hydrogen" total 13,063 documents were found. But when used terms in combination "Green Hydrogen" AND Adoption OR "adoption behaviour" then total 569 documents received. Further "Green Hydrogen" AND Adoption OR "adoption behaviour" AND Decarbonization OR Decarbonizations the total161documents were found. However, after filters application of Article and Review Papers only 118 documents identified and excluded Book Chapters, Book, Conference Papers etc. After in-depth systematic literature review some major challenges were identified like high production cost, limited energy supply, infrastructure gaps, policy and regulatory uncertainty, technological immaturity, high storage & transport cost, competition from alternatives, and lack of demand certainty. While progress is being made, overcoming these barriers will be essential for green hydrogen to play a transformative role in the global energy transition.

Keywords: Green hydrogen; energy; barriers; adoption; behaviour

1. Introduction

The global push to decarbonize has increased the demand for sustainable energy substitutes and green hydrogen has emerged as a vital solution to cut down carbon emissions across industries (IEA, 2021). Green hydrogen, produced by electrolysis from electricity generated by renewable energy sources, provides a clean alternative to fossil fuels, especially in hard-to-abate sectors such as heavy industry, transport and energy storage (IRENA, 2022). But there are major barriers to the widespread adoption of green hydrogen, despite its promise, including high production costs, technological limitations, infrastructure deficits and policy uncertainties (Hosseini,2023).
Green hydrogen, produced through electrolysis using renewable energy, is increasingly seen as a key enabler of decarbonisation in hard-to-abate sectors such as heavy industry, shipping and aviation (IRENA, 2021). However, widespread adoption faces many barriers, including high production costs, limited supply of renewable energy, infrastructure gaps, policy uncertainty, technological immaturity, high storage and transport costs, competition from alternatives and lack of demand certainty.

2. Literature Review

This literature review examines these challenges, drawing on recent academic and industry sources. In the Scopus database key words used "Green Hydrogen" total 13,063 documents were found. But when used terms in combination "Green Hydrogen" AND Adoption OR "adoption behaviour" then total 569 documents received. Further "Green Hydrogen" AND Adoption OR "adoption behaviour"

AND Decarbonization OR Decarbonizations the total161documents were found. However, after filters application of Article and Review Papers only 118 documents identified and excluded Book Chapters, Book, Conference Papers etc. After in-depth systematic literature review some major challenges were identified like high production cost, limited energy supply, infrastructure gaps, policy and regulatory uncertainty, technological immaturity, high storage & transport cost, competition from alternatives, and lack of demand certainty.

2.1 High Production Costs

One of the most significant barriers to green hydrogen adoption is its high production cost compared to conventional hydrogen derived from fossil fuels (grey and blue hydrogen). According to the International Energy Agency (IEA, 2022), green hydrogen production costs range between $3-$8/kg, whereas grey hydrogen costs approximately $1-$2/kg. The main cost drivers are expensive electrolyzers and high capital expenditure (CAPEX) for renewable energy integration (Glenk et al., 2023). Costs are expected to fall due to falling renewable power prices and economies of scale, but green hydrogen is not yet commercially competitive without large subsidies or a carbon price (Boretti, 2021).

2.2 Limited Renewable Energy Supply

Green hydrogen production that is viable requires abundant, low-cost renewable electricity. But many regions do not have enough renewable energy capacity to allow for large scale hydrogen production (IRENA, 2021). The intermittent nature of wind and solar power is also a challenge, which needs energy storage or grid-balancing solutions (Gutiérrez-Martín et al., 2022). Some studies have suggested co-locating hydrogen production with offshore wind farms to overcome this problem, but this would require large investments in infrastructure (Reuß et al., 2023).

2.3 Infrastructure Gaps

Current hydrogen infrastructure is mostly designed for fossil-based hydrogen and is inadequate for large-scale deployment of green hydrogen (IEA, 2022). The key infrastructure challenges are the absence of hydrogen transport pipelines, a limited number of refueling stations, and the lack of port facilities for export of hydrogen (Haase et al., 2021). Natural gas pipelines can be converted for hydrogen use, but require material compatibility assessments and regulatory approval (Melaina et al., 2022).

2.4 Policy & Regulatory Uncertainty

Investment in green hydrogen projects is impeded by policy frameworks that are uncertain and unstable (IRENA, 2021). Some nations, including Germany and Australia, have adopted hydrogen strategies, but numerous countries still lack specific regulations on safety standards, certification, and market incentives (Glenk et al., 2023). Mixed carbon pricing and subsidy schemes also generate uncertainty for investors (Boretti, 2021). Accelerating market development requires a harmonised international regulatory framework (IEA, 2022).

2.5 Technological Immaturity

Although electrolyzer technologies, such as PEM and alkaline, are commercially available, they still face challenges in efficiency and durability (Gutiérrez-Martín et al., 2022). We need innovations in catalyst materials and manufacturing processes to lower costs and improve performance (Reuß et al., 2023). Additionally, large-scale hydrogen storage solutions, including salt caverns and liquid hydrogen systems, are still in development (Haase et al., 2021).

2.6 High Storage & Transport Costs

Hydrogen has a low energy density by volume, which makes storage and transportation expensive (Melaina et al., 2022). Compressed and liquefied hydrogen need a lot of energy to process. Alternative carriers, like ammonia or liquid organic hydrogen carriers (LOHCs), also bring extra challenges and costs (IRENA, 2021). It is essential to develop affordable transport solutions, such as hydrogen pipelines or shipping ammonia by sea, to support global trade (IEA, 2022).

2.7 Competition from Alternatives

Green hydrogen competes with other low-carbon technologies, including battery electrification and biofuels (Boretti, 2021). In areas like road transport, batteries tend to be more energy-efficient. Biofuels provide a drop-in solution for aviation and shipping (Glenk et al., 2023). Hydrogen's competitiveness relies on improvements and cost cuts in electrolysis and fuel cells (Gutiérrez-Martín et al., 2022).

2.8 Lack of Demand Certainty

In sectors such as steelmaking, chemicals, and shipping, end-users still have reservations about investing in green hydrogen due to uncertainties in terms of price and supply. The lack of offtake agreements makes it difficult for projects to obtain funding (IRENA, 2021). The government could create market demand by imposing mandatory quotas (IEA, 2022).

3. Results and Analysis

After collection of data bibliometric analysis performed in the RStudio. Figure1 tree map reflects green hydrogen term used 55 times and 7% of all word's frequency. Further 52 times decarbonization and 6% of total words.

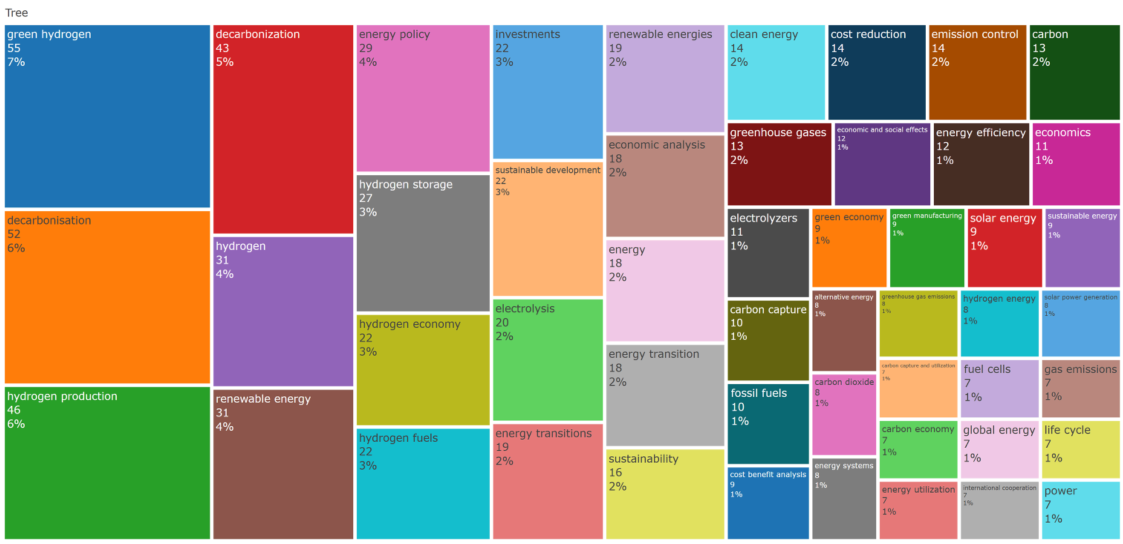

Figure 1: Tree map

Figure 2 also reflects word frequency reflected highest green hydrogen, decarbonization and hydrogen production.

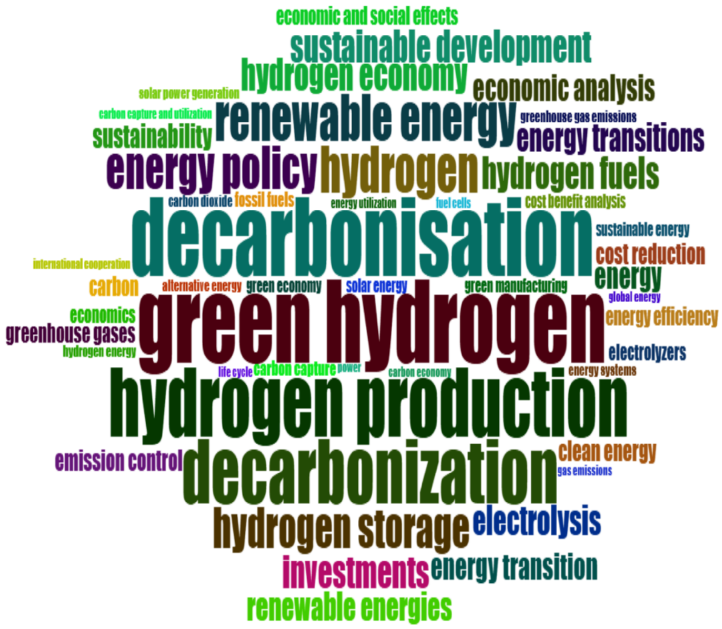

Figure 2: Word cloud

Figure 3 reflects most relevant journal for this study International Journal of Hydrogen Energy, Energies, Renewable and Sustainable Energy Reviews etc.

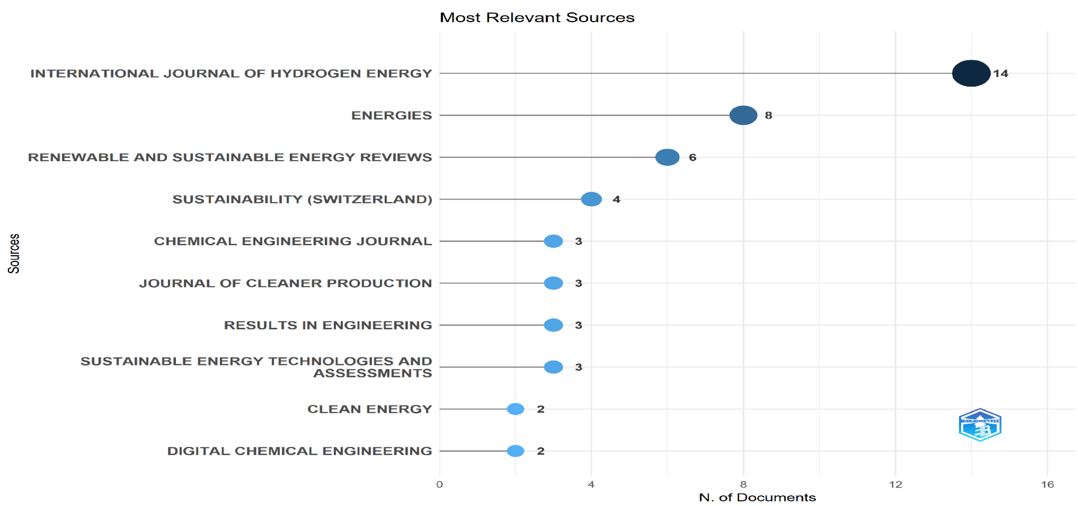

Figure 3: Most relevant sources

4. Conclusion

The use of hydrogen is being held back by a lot of problems that are all connected. These problems include the cost the fact that we do not have the infrastructure the rules and regulations are not in place and the technology is not good enough. To fix these problems the government, companies and research centres need to work. They need to make green hydrogen cheaper increase the amount of energy we use build the infrastructure we need and create rules that support the use of green hydrogen. While we are making progress, we need to get rid of these problems if we want green hydrogen to really change the way we think about energy. This report looks at what we know about the problems that are stopping us from using hydrogen and will help us do more research and make new policies, about green hydrogen.

References

1. Boretti, A. (2021). "Cost challenges of green hydrogen for heavy transport." *Energy Reports, 7*, 5752-5761.
2. Glenk, G., Reichelstein, S., & Rieger, A. (2023). "Economics of green hydrogen production." *Nature Energy, 8*(3), 210-221.
3. Gupta, V., Gupta, A., & Nagar, A. (2026). Unveiling behavioural intentions for hydrogen fuel cell vehicle adoption for sustainable development: Leveraging partial least square–structured equation modelling and fuzzy set qualitative comparative analysis. *International Journal of Hydrogen Energy*, *238*, 155278.
4. Gutiérrez-Martín, F., et al. (2022). "Challenges in scaling up electrolyzers for green hydrogen." *Renewable and Sustainable Energy Reviews, 156*, 111935.
5. Haase, M., et al. (2021). "Hydrogen infrastructure needs for decarbonization." *Applied Energy, 290*, 116735.
6. IEA. (2022). *Global Hydrogen Review 2022*. International Energy Agency.
7. IRENA. (2021). *Green Hydrogen Cost Reduction: Scaling Up Electrolyzers*. International Renewable Energy Agency.
8. Melaina, M., et al. (2022). "Hydrogen pipeline networks for energy transport." *Energy Policy, 163*, 112825.
9. Reuß, M., et al. (2023). "Offshore wind-to-hydrogen: Economic feasibility." *Energy Conversion and Management, 276*, 116543.
10. Serik, A., Kuspanov, Z., & Daulbayev, C. (2026). Cost-effective strategies and technologies for green hydrogen production. *Renewable and Sustainable Energy Reviews*, *226*, 116242.