MAPPING COLLABORATION AND INNOVATION IN GREEN HYDROGEN RESEARCH: A SOCIAL NETWORK ANALYSIS APPROACH

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Extended Abstract

1. Introduction

Hydrogen is emerging as a key energy vector in the green transition, playing a crucial role in decarbonizing critical sectors such as energy, transportation, and heavy industry (Liu et al., 2020). Studies on the application of the Triple Helix Model (Etzkowitz & Leydesdorff, 2000) in the hydrogen sector have demonstrated its effectiveness in fostering collaboration between academia, industry, and government, leading to accelerated innovation and commercialization (Baquero & Monsalve, 2024; Musiolik et al., 2012). In this context, the Hydrogen Research Operational Plan (POR H2) represents one of the most significant national initiatives in Italy, aiming to develop a competitive hydrogen value chain. The project involves a wide network of research institutions, companies, and public entities, emphasizing the collaborative component essential for technological innovation (Carayannis & Campbell, 2009). This study builds upon the theoretical advancements of the Triple Helix Model, whose applications confirm its potential to foster innovation. By applying Social Network Analysis (SNA), we analyze the relationships that have emerged within the POR H2 network, identifying the flow of resources among stakeholders, the activation of collaborations, and the creation of PhD scholarships focused on hydrogen research. The study thus aims to map the flow of knowledge and the innovation potential within the hydrogen sector in Italy.

2. The Strategic Role of Hydrogen in the Green Transition

Hydrogen, particularly green hydrogen, is a priority solution for medium-term energy system decarbonization. Globally and nationally, it represents an opportunity to reduce reliance on fossil fuels and enhance energy security. The hydrogen value chain, including production, storage, distribution, and final use, is a key focus of European and Italian research and development efforts.
The POR H2 initiative is embedded within this context, striving to reinforce Italy's position in the emerging hydrogen sector. Collaborative research efforts among the network participants are fundamental in achieving these ambitious decarbonization objectives.
Public policies play a pivotal role in the development of green hydrogen. The European Union and Italy have established funding mechanisms, strategic roadmaps, and regulatory frameworks to foster research, innovation, and industrial application of hydrogen technologies. The European Hydrogen Strategy (European Commission, 2020) outlines a roadmap for hydrogen deployment, emphasizing production from renewable sources and large-scale market adoption by 2050. Additionally, the Italian National Hydrogen Strategy (MASE, 2024) defines national objectives, promoting hydrogen as a key vector for decarbonization through targeted investments, pilot projects, and sector integration.
The Triple Helix Model provides a theoretical foundation for understanding how these policy initiatives shape the interactions between universities, industry, and government. By fostering a networked approach, these policies encourage interdisciplinary research, technology transfer, and the creation of innovation clusters within the hydrogen sector. The European and Italian hydrogen strategies serve as catalysts that incentivize joint ventures, funding programs, and collaborative research projects. This structured support mechanism enhances the capacity of knowledge institutions to engage with industrial partners while

aligning technological advancements with policy objectives, thereby accelerating the commercialization and scalability of hydrogen technologies.

3. Research Methodology

This study employs a mixed-method approach, integrating Social Network Analysis (SNA) (Wasserman & Faust, 1994) with a qualitative assessment of collaborative mechanisms within the POR H2 initiative. SNA is used to map the relationships between key stakeholders, including research institutions, industry partners, and governmental bodies, to analyze the structure and density of these connections. This enables the identification of knowledge hubs, collaboration patterns, and the flow of research funding.
To achieve a more detailed network analysis, several key SNA metrics are employed:

- Degree centrality: This metric measures each actor's direct connections within the network, highlighting influential institutions that serve as key intermediaries in knowledge dissemination.
- Betweenness centrality: This indicator identifies actors that play a bridging role between different parts of the network, facilitating the transfer of resources and information between otherwise disconnected groups.
- Closeness centrality: It assesses how quickly an entity can access information within the network, which is crucial for understanding efficiency in knowledge flow and innovation diffusion.
- Network density: This metric evaluates the overall level of connectivity in the network, providing insights into the degree of collaboration among stakeholders.

Additionally, the study evaluates the impact of POR H2 in fostering innovation by analyzing research outputs such as academic publications, patents, and PhD scholarships. These metrics provide insights into the effectiveness of the network in knowledge dissemination and technological advancements. The combination of these methods allows a comprehensive understanding of how research collaboration translates into innovation and commercialization.

4. Expected Outcomes

By applying SNA to the POR H2 initiative, the study aims to provide a clearer understanding of how knowledge and resources circulate among the actors involved. The results are expected to highlight the key players in the network and the extent to which interdisciplinary collaboration contributes to advancing hydrogen technology. Furthermore, the study seeks to quantify the impact of this collaboration by analyzing the production of academic publications, patents, and funded doctoral programs in hydrogen research. This evaluation will offer insights into the real contribution of the initiative to scientific progress and technological innovation in the hydrogen sector.

5. Implications for Policy and Future Research

The findings of this study will be valuable for policymakers and stakeholders in the hydrogen sector, offering evidence-based recommendations on how to optimize collaboration for greater innovation outcomes. By identifying potential gaps in the network, the study will suggest strategies for strengthening interdisciplinary and cross-sectoral partnerships.
Future research should focus on refining metrics for assessing the long-term impact of research collaborations, particularly regarding the commercialization of patents, industrial applications, and international cooperation in hydrogen innovation. Expanding the scope of the study to include additional hydrogen-related projects and international partnerships could further enhance the understanding of best practices in fostering sustainable technological innovation

6. References

Baquero, J. E. G., & Monsalve, D. B. (2024). From fossil fuel energy to hydrogen energy: Transformation of fossil fuel energy economies into hydrogen economies through social entrepreneurship. *International Journal of Hydrogen Energy*, *54*, 574-585.

Carayannis, E. G., & Campbell, D. F. J. (2009). 'Mode 3' and 'Quadruple Helix': Toward a 21st-century fractal innovation ecosystem. *International Journal of Technology Management*, 46(3-4), 201-234.

European Commission. (2020). A Hydrogen Strategy for a Climate-Neutral Europe. Brussels: European Commission. https://ec.europa.eu/energy/hydrogen-strategy

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research Policy*, 29(2), 109-123.

Liu, W., Sun, L., Li, Z., Fujii, M., Geng, Y., Dong, L., & Fujita, T. (2020). Trends and future challenges in hydrogen production and storage research. *Environmental science and pollution research*, *27*, 31092-31104.

Ministero dell'Ambiente e della Sicurezza Energetica (MASE) (2024). Strategia Nazionale Idrogeno https://www.mase.gov.it/sites/default/files/Strategia%20Nazionale%20Idrogeno.pdf

Musiolik, J., Markard, J., & Hekkert, M. (2012). Networks and network resources in technological innovation systems: Towards a conceptual framework for system building. *Technological Forecasting and Social Change*, *79*(6), 1032-1048.

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research policy*, *45*(8), 1620-1635.

Wasserman, S., & Faust, K. (1994). *Social Network Analysis: Methods and Applications*. Cambridge University Press.