

THE ROLE OF INDUSTRIAL CLUSTERS IN THE DEVELOPMENT OF THE HYDROGEN ECONOMY: A COMPARISON BETWEEN UNITED STATES, EUROPE, AUSTRALIA

Kalyne Brito^{1*}, Ana Carolina Chaves¹, Thereza Aquino¹, Luiza Masseno¹ and Caroline Chantre¹

¹ Grupo de Estudos do Setor Elétrico (GESEL), Federal University of Rio de Janeiro, Brazil

* Corresponding author: kalyne.brito@gesel.ie.ufjf.br, Grupo de Estudos do Setor Elétrico, Rio de Janeiro, Brazil

KEYWORDS

Hydrogen Economy; Hydrogen Industrial Clusters, Public Policies.

ABSTRACT

Despite the optimistic prospects for the low-carbon hydrogen economy, several challenges need to be solved for the development of this new market, such as uncertainties in future hydrogen demand. One approach being proposed to jump start the industry involves the development of hydrogen clusters (hubs or valleys). The literature points out that industrial cluster models make it possible to take advantage of the energy infrastructure and industries present in ports and industrial clusters to make them strategic centers for the expansion of hydrogen production and use. In this context, the objective of this article is to analyze the public policies that have been implemented to develop hydrogen industrial clusters, considering the cases of the European Union, the United States and Australia. The qualitative analysis was carried out based on a literature systematic review. Based on the experience of these regions, the article outlines perspectives for the Brazilian case, considering the development of new projects and the potential of networks of hydrogen producers and potential users around the port infrastructure.

INTRODUCTION

The interest in developing a hydrogen market has grown in recent years to ensure compliance with the goals established in the Paris Agreement and the decarbonization of sectors of the economy, especially hard-to-abate sectors. Recently, there has been a considerable increase in the number of hydrogen projects announced around the world. In according to IRENA (2022) the first hydrogen projects are expected to be developed close to large demand centers, including ports and industrial clusters, as they require a high volume of hydrogen and take advantage of economies of scale to reduce costs. The deployment of clean hydrogen industrial clusters (hubs or valleys) can rapidly support market development, be based on tested economic structures to create efficient and effective industrial activity, through government-supported geographic clusters. UNIDO (2023) defines hydrogen industrial clusters as industrial regions or clusters that share clean hydrogen production, transport and uses, and renewable electricity (solar, hydro or wind power), as well as other resources for other purposes, like mobility, heating and cooling and industrial feedstock. These types of clusters are characterized by internal connections that allow cooperation, specialization experience, services, resources, suppliers, and skills, and also generate several advantages among participants, including investment distribution and risk mitigation. Other benefits include access to raw materials, transportation and transmission systems, and a well-trained labor pool. Additionally, data provided by hydrogen hub could be used in future analysis to identify approaches and initiatives to leverage hydrogen market (US Government, 2023).

Until 2023, there are 90 hydrogen industrial cluster mapped by Clean Hydrogen Partnership (CHP) and Mission Innovation (MI), 74% located in Europe, followed by Australia (4%), United States of America (4%) and China (3%) (CHP and MI, 2024). Therefore, the purpose of this paper is to analyze the role of industrial clusters in the development of the hydrogen economy at the global level, considering the cases of Europe, United States of America (USA), and Australia. Based on the experience of these regions, the article outlines perspectives for the Brazilian case and presents

a set of policies identified in international experience that can accelerate the development of these industrial clusters, bringing recommendations for national experience.

METHODS

The research was carried out through a systematic literature review with bibliometric analysis, which aims to present the state of the art and international experience on the development of hydrogen industrial clusters. The review aimed to identify hydrogen industrial cluster models and public policies associated with the development of these initiatives, using “hydrogen hubs”, “hydrogen valleys” and “hydrogen clusters” as search strings. For this purpose, a search was carried out in the *Scopus* and *Web of Science* databases, selecting only articles in the areas of economics, energy, social sciences and interdisciplinary. For this purpose, the *R software* and the *bibliometrix* package were used, which analyzes the metadata extracted from the databases used, enabling a qualitative and quantitative analysis of the productions selected through the *Biblioshiny* platform (Aria and Cuccurullo, 2017). The survey resulted in a database with 80 papers, of which only 23 were selected for analysis after reading the titles and, subsequently, the abstracts. After carrying out the systematic review, a documentary search was carried out on the websites of government agencies, institutions, and companies, which resulted in 16 documents.

Based on the analysis of the results on the *Biblioshiny* platform, it was identified that publications were concentrated from 2020 onwards and the USA, European countries, Singapore, China, Indonesia, Korea, and Australia are the regions most cited in the publications found. However, in accordance with the Hydrogen Valley Platform, Singapore, Indonesia, and Korea do not have any hydrogen industrial cluster initiatives. For this reason, they were not considered in this analysis. The Hydrogen Valley Platform points out that Europe, the USA, and Australia have the highest number of announced hydrogen hubs. Due to that, these regions were selected to evaluate and analyze the industrial, incentive, environmental, innovation and technological policies that have been implemented to guarantee the development of hydrogen industrial clusters.

RESULTS

This section will present the public policies that have been implemented by Australia, USA and Europe to develop hydrogen hubs.

United States

In 2021, the USA government announced the Infrastructure Investment and Jobs Acts (IIJA), also known as the Bipartisan Infrastructure Law (BIL), including US\$8 billion to demonstrate the development of clean hydrogen hubs through the Regional Clean Hydrogen Hub Program (H2Hubs). In 2023, the program's funding call selected 7 hydrogen hubs, which will collectively receive more than \$40 billion in private investment, producing more than 3 million tons of clean hydrogen per year (US Department of Energy, 2023a). The program is part of the National Hydrogen Strategy to develop hydrogen infrastructure regionally, forming the foundations for a national clean hydrogen network. Associated with the H2Hubs Program, the US government announced other policies that could boost the development of clean hydrogen hubs in the country. These initiatives can be seen in Table 2.

Table 2: Public policies to support the formation of clean hydrogen hubs in the USA.

	Policy	Summary
Financial incentives	Clean Hydrogen Regional Hubs	Financial support to establish up to 7 regional clean hydrogen hubs across the country.
	Port Infrastructure Development Grants	Offers grants for projects that improve port climate change resiliency, as well as projects that reduce or eliminate port-related criteria pollutant or greenhouse gas emissions.
	Port Electrification Grants	Clean Ports grant program for the purchase or installation of zero emission port equipment or technology.
	Energy Infrastructure Reinvestment Program	Loans to projects that retool, repower, repurpose, or replace energy infrastructure that has ceased operations; or enable operating energy infrastructure to avoid, reduce, utilize, or sequester air pollutants or anthropogenic emissions of greenhouse gases.
Tax Credits Incentives	Inflation Reduction Act (IRA)	The IRA incentives reduce renewable energy costs for organizations, and also clean hydrogen producers are eligible for a tax credit of up to \$3 per kilogram (kg) of clean hydrogen produced.
Regulation	Clean Hydrogen Production Standard	Establish a target of 4 kgCO _{2(eq.)} /kg hydrogen for lifecycle greenhouse gas emissions associated with hydrogen production.

The public perception of hydrogen is a key aspect to develop hydrogen hubs, to address that the applicants for H2Hubs program need to implement a community benefits plan to build public support, carry out labor engagement and creating good-paying jobs, which is also a criterion to take IRA's benefits. The initiatives taken by the USA government aimed to guarantee hydrogen production and demand at a low cost.

Australia

In 2019, the Australian government released its National Hydrogen Strategy, which describes an adaptive approach to industry development that supports and refines actions as technology and markets change. One of the key elements to this approach is the development of hydrogen hubs, as a kickstart to boost domestic demand for hydrogen. Additionally, the government of each Australian state has also exhibited full support for the national hydrogen plans.

Australia's National Hydrogen Strategy supports the National Energy Resources Australia (NERA) to establish a National Hydrogen Technology Cluster in partnership with state territory government, which aims to build capabilities and facilitate industry collaboration across the hydrogen value chain. In 2020, NERA launched the Regional Hydrogen Technology Clusters Seed Funding Program to support the development of regional hydrogen clusters in Australia, through which identify 13 regional hydrogen industrial clusters (CSIRO, 2021). Also, through a Regional Hydrogen Hub Program, the Australian Government invested AUD \$526 million to support the development of 8 hydrogen hubs in the country (Government of Australia, 2023). Table 1 shows a synthetic mapping of public policies to support the formation of clean hydrogen hubs in Australia.

Table 1: Public policies to support the formation of clean hydrogen hubs in Australia.

Aspects	Policy	Policy description
Financial incentives	Hydrogen Headstart Program	AUD\$2 billion Federal Budget, would provide revenue support for large-scale renewable hydrogen projects through competitive hydrogen production contracts.
	Regional Hydrogen Hubs Program	Over AUD\$500 million is being made available to support 8 hydrogen hubs across Australia.
	Australian Renewable Energy Agency's Funding	Over AUD\$280 million to hydrogen R&D projects, feasibility studies, pilot and demonstration plants.
	Clean Energy Finance Corporation Advancing Hydrogen Fund	Up to AUD\$ 300 million in debt and equity finance to invest in projects that align with the National Hydrogen Strategy.
International partnerships	Australia-Germany	Under the partnership the countries support real-world pilot, trial, demonstration and research projects along the hydrogen supply chain; exploring options to facilitate the trade of hydrogen and its derivatives produced from renewables and facilitating industry-to-industry cooperation on demonstration projects in Australian hydrogen hubs.
	Australia-Japan	A commitment to jointly support initiatives to help drive the transition to net zero emissions.
Regulation	National Hydrogen Codes of Best Practice	Provide an overview of key Commonwealth regulation which may be relevant to hydrogen projects.

In conclusion, the initiatives taken by the Australian government, aimed at the large-scale production of hydrogen and the construction of robust infrastructure and logistics, demonstrate that the country will be one of the main exporting countries of hydrogen for Asian markets until 2030. For the 2050 horizon, the country intends to become a major global exporter of clean hydrogen, depending on requirements and demands. In a complementary way, it is important to highlight that the government expects economic growth that will encourage new businesses and jobs, as well as the opportunity for Australia to offer equipment, technologies, technical safety standards, education and training to the whole world, thus supporting development of national and international technology (COAG, 2019).

Europe

In 2020, the European Commission (EC) published the EU Hydrogen Strategy, setting the goal of achieving approximately 13-14% renewable hydrogen share in the energy matrix. Currently, hydrogen accounts for less than 2% (Notteboom e Haralambides, 2023). The EU Hydrogen Strategy indicates that the development of clean hydrogen production in Europe is divided into three main phases. It is expected that the deployment of hydrogen hubs will occur extensively during the period from 2025 to 2030 (Phase 2). Currently, some hydrogen hubs under development in the EU already go beyond simple RD&I projects and reach larger scales and a variety of consumers (Weichenhain et al.,

2022). The countries in Europe with the largest number of hydrogen hubs under development are: i) Germany, with five projects; ii) Netherlands, Spain and France, with three projects; iii) United Kingdom, with two projects iv) other countries, with only one project, are Denmark, Belgium, Italy and Portugal (Genovese et al., 2024).

In view of the nascent clean hydrogen industry, public policies to encourage hubs, at this first stage, encompass direct financial support and tax incentives aimed at RD&I, production, infrastructure, and demand. According to Włodarczyk and Kaleja (2023), by 2050, the total amount spent by the EU on hydrogen infrastructure development could range between 180 and 470 billion euros. Some port authorities, in cooperation with industry, contribute to creating a good business environment for universities, companies focused on RD&I, research centers, consultancy companies and start-ups. In general, this is done through partnerships in EU-funded projects, the establishment of research areas and PhD funding, collaboration through hydrogen platforms, etc. (Notteboom and Haralambides, 2023). Table 3 presents a synthetic mapping of public policies to support the formation of clean hydrogen hubs. It is worth noting that this analysis was restricted to the macro policies established by the European Union and did not include specific policies implemented within each Member State.

Table 3: Public policies to support clean hydrogen hubs in the European Union

Aspects	Policy	Policy description
Financial incentives	Important Projects of Common European Interest (IPCEI)	It allows projects to receive public support beyond the usual limits of state aid rules. IPCEIs are ambitious, cross-border and integrated projects, important because of their contribution to EU objectives. Project approvals total 76, with 10 billion euros.
	Horizon Europe	Pillar II and III of Horizon Europe are of specific interest for the deployment of low carbon industry applications and breakthrough technologies, including hydrogen.
	NextGen-EU	Key objectives of these grants: boosting innovation, ecological transition, economic recovery, territorial cohesion, and the fight against climate change.
	European Hydrogen Bank (EHB)	Utilizing the resources from the Innovation Fund, the bank will subsidize the nascent market for renewable hydrogen, encompassing both domestic and international spheres.
	Connecting Europe Facility (CEF)	Program for the development of cross-border infrastructure can now support projects for electrolyzers, hydrogen pipelines, storage and conversion/reconversion facilities based on an update of the TEN-E regulation.
	European Just Transition Fund	It supports a diversification of economic activity, creating new business opportunities and helping people adapt in a changing labor market. It can support, in industrial facilities, investments that reduce greenhouse gas emissions from activities listed in Annex I of the EU Emissions Trading Scheme Directive (ETS).
Public-private partnerships	Clean Hydrogen Partnership	Funding to develop hydrogen technologies in different areas, including renewable hydrogen production, hydrogen valleys, storage, distribution and transport
	Hydrogen Valley Platform	The platform provides comprehensive insights into the world's most advanced and ambitious Hydrogen Valleys. It is an initiative under Mission Innovation, which aims to achieve the milestone of 100 Hydrogen Valleys by 2030. In the next stages, efforts will be made to enhance the attractiveness of the platform, identify barriers and best practices of the valleys or hubs, and expand international cooperation.
Regulation	Renewable Energy Directive II (RED II)	Production from renewable electricity (or grid electricity with <65 g CO ₂ -eq/kWh) meeting criteria on temporal and geographical correlation and additionality of renewable generation.
	The European Clean Hydrogen Alliance	Published in March 2023 a roadmap on hydrogen standardization.
	European Hydrogen Safety Panel (EHSP)	Guidance on Safety Planning and Management in EU hydrogen and fuel cell projects.

These specific policies aim to create an enabling environment for the formation of clean hydrogen industrial hubs in Europe, encouraging investment, promoting innovation, and contributing to decarbonization in key industrial sectors.

DISCUSSION

Brazil also has been developing hydrogen hubs initiatives and work on public policies propositions to enable the formation of low-carbon hydrogen market. The most recent advance was the development of the National Hydrogen Program (PNH2) and its Three-Year Work Plan (2023-2025), which proposes a set of actions for the development of the hydrogen economy (MME, 2023). Among the suggestions are the analysis and estimation of the potential for the development of hydrogen and derivatives export hubs; and the identification of potential improvements in the regulatory framework for Export Processing Zones (EPZ), to encourage the development of projects. In addition to

the suggestions contained in the PNH2, some initiatives are already underway. One example is the implementation of tax benefits for low-emission projects located in export zones, already available in the state of Ceará and Piauí and under discussion in the states of Rio de Janeiro and Pernambuco (IEA, 2022). Table 4 summarizes other hydrogen hubs initiatives in Brazil and their specifications.

Table 4: Specifications for clean hydrogen industrial clusters and potential hydrogen clusters in Brazil

Brazilian hydrogen hubs	Regional Strategy	Financial			Other regional incentives	Ports	End use	Value chain coverage
		National	International	Private				
Green Hydrogen Hub at Pecém Port	Yes	No	Yes	Yes	Yes	Yes	Mobility, Energy and industrial feedstock	Energy supply, production, storage and transport
Green Energy Park Piauí	Under development	Yes	Yes	Yes	Yes	Yes	Industrial feedstock	Energy supply, production, storage and transport
Low-carbon hydrogen and its derivatives hub at Açú Port, Rio de Janeiro	Under development	No	No	Yes	Yes	Yes	Industrial feedstock, mobility	Energy supply, production, storage and transport
Green hydrogen TechHub at Port of Suape, Pernambuco	Yes	No	Yes	Yes	No	Yes	Industrial feedstock	Energy supply, production, storage, and transport

Mans et al (2008) point out that, generally, regions considered potential hydrogen hubs have a clear motivation for doing so. The authors identify a set of elements common to the different hubs: presence of related industries (e.g. Rotterdam has a large chemical industry, which produces hydrogen as a by-product), presence of branches of large sectoral players in the region and universities and research centers carrying out R&D in the region. In the Brazilian case, some other elements can be observed: the availability and potential associated with solar and/or wind generation (in the case of Ceará), the region's specialization in the O&G industry (in the case of Açú) and, unanimously, the proximity of ports located in EPZ, with capacity and experience in large-scale exports.

Despite the recent advances in hydrogen policies in Brazil, there is a lack of clarity in the hydrogen industry incentives and regulation, and the need for government coordination still generate uncertainty among investors (Garlet et al, 2024). Australia, the United States and Europe have been focused on establishing different mechanisms for the development of hydrogen hubs, especially financing mechanisms for hydrogen projects. In Brazil there are financing lines available for hydrogen projects, but the volumes are not comparable to those in the regions analyzed. Therefore, regional, state and/or municipal tax incentives are important investment promotion mechanisms, as they contribute to reducing costs and increasing the competitiveness of clean hydrogen. To this end, the combination of public and private efforts is essential, as well as the alignment of the sector's encouraging interests. In the Brazilian case, the hydrogen production can also be integrated with port concessions and EPZ incentives, in which there is a paid transfer of a certain area for the implementation of clean hydrogen production plants or a concession that provides for the implementation of gas pipelines, to enable the clean hydrogen internal transport. Successful examples of integrating port concessions with hydrogen projects is the Port of Suape and Port of Pecém (Souza, 2021).

CONCLUSIONS

Hydrogen hubs are one of the best responses to expanding the hydrogen economy, as they bring together the production, storage, distribution, and end use of hydrogen in fully functional and sustainable local or regional value chains. By deploying hubs, they create ecosystems where research and innovation can be tested and find immediate use, leading to new advances in the hydrogen sector. Hubs combine different business models, from upstream to downstream, and form partnerships through long-term contracts, which can serve to finance the business, in addition to reducing risk.

The inclusion for the formation of cluster can be an important addition to hydrogen energy policy. However, only an industrial policy may not be enough to achieve hydrogen market development objectives. Australia, US and Europe have been implementing several public policies and other initiatives to support hydrogen production and use, as well as the construction of robust hydrogen infrastructure and logistics. To guarantee the hydrogen market growth in Brazil will be required incentives for institutions; establish cooperation between policy makers, companies, academia. Furthermore, within the legislative and standardization framework, it is essential to reach international agreements that allow the production, export/import, and use of clean hydrogen through clear and fair rules, thus favoring the international hydrogen market. Some public policies aimed at accelerating the installation of hydrogen hubs can act in several areas: stimulating research and development in technologies in the hydrogen production chain; regional financial incentives to attract private investors; stimulate the training of the workforce with skills and abilities necessary for an industry with important safety requirements.

ACKNOWLEDGMENTS

The authors thank EDP for the financial support to the research and all the researchers and other collaborators, who provided expertise that greatly assisted the research. This research is a National Electric Energy Agency (ANEEL) R&D Project financed by the EDP.

REFERENCES

- Aria, M.; Cuccurullo, C. 2017. bibliometrix: An R-tool for comprehensive science mapping analysis, *Journal of Informetrics*, No.4 (Nov.), 959-975.
- CHP and MI. 2024, *Hydrogen Valley Map*, Clean Hydrogen Partnership and Mission Innovation. Available: <https://h2v.eu/hydrogen-valleys>.
- COAG. 2019. Australia's National Hydrogen Strategy, *Department of Climate Change, Energy, the Environment and Water*. Available: <https://www.dcccew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf>
- CSIRO. 2021. NERA. *HyResource*. Available: <https://research.csiro.au/hyresource/organisations/nera/>.
- Garlet, T.; Savian, F.; Ribeiro, J.; Siluk, J. 2024. Unlocking Brazil's green hydrogen potential: Overcoming barriers and formulating strategies to this promising sector, *International Journal of Hydrogen Energy*, v. 49, Part D, p. 553-570.
- Genovese, M.; Piraino, F.; Fragiaco, P. 2024. 3E analysis of a virtual hydrogen valley supported by railway based H₂ delivery for multi-transportation service, *Renewable and Sustainable Energy Reviews*, v. 191, p.114070.
- IEA. 2022. Global hydrogen review 2022, *International Energy Agency*.
- IRENA. 2022. Global hydrogen trade to meet the 1.5°C climate goal: Part I – trade outlook for 2050 and way forward, *International Renewable Energy Agency*, Abu Dhabi.
- Mans, P.; Alkemade, A.; van der Valk, T. Hekkert, M. P. 2008. Is cluster policy useful for the energy sector? Assessing self-declared hydrogen clusters in the Netherlands, *Energy Policy*, v. 36, No 4 (Apr.), 1375-1385.
- MME. 2023. National Hydrogen Program: Three-Year Work Plan 2023-2025, *Ministry of Mines and Energy*.
- Notteboom, T.; Haralambides, H. 2023. Seaports as green hydrogen hubs: advances, opportunities and challenges in Europe, *Maritime Economics & Logistics*, v. 25 (Feb.), 1-27.
- Souza, L.; Mendonça, A. C. G.; Furtado, G. R. 2021. Viability of green hydrogen hubs in Brazil. *Legal Intelligence Center*, Machado Meyer Advogados. Available: <https://www.machadomeyer.com.br/en/recent-publications/publications/financing-and-infrastructure-projects/viability-of-green-hydrogen-hubs-in-brazil>.
- UNIDO, United Nations Industrial Development Organization. 2023. Green hydrogen industrial clusters guidelines, Vienne.
- US Department of Energy. 2023. Regional Clean Hydrogen Hub Selections for Award Negotiations, *Office of Clean Energy Demonstrations*. Available: <https://www.energy.gov/oced/regional-clean-hydrogen-hubs-selections-award-negotiations>
- Weichenhain, U.; Kaufmann, M.; Hölscher, M.; Scheiner, M. 2022. Going global: An update on Hydrogen Valleys and their role in the new hydrogen economy. *Clean Hydrogen Partnership*.
- Włodarczyk, R.; Kaleja, P. 2023. Modern hydrogen Technologies in the face of climate change – analysis of strategy and development in polish conditions, *sustainability*, v. 15, n. 17, p. 12891.