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Short Report

The Brazilian Research Scenario in Green Hydrogen: A Brief Contextualization

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Abstract

Hydrogen is crucial in various industrial sectors and can be obtained through different synthesis routes. However, a significant portion of its production still relies on chemical processes involving fossil fuels, resulting in hydrogen and the generation of greenhouse gases (GHGs) as the final byproduct. In alignment with the goals of the 2030 Agenda, where countries commit to implementing energy transition, hydrogen obtained through a green route has been increasingly explored by governmental and academic entities as an alternative energy source. Numerous studies and projects related to its production and use are being promoted. Within this context, this work aims to provide a concise overview of various topics and contextualizations associated with the use of hydrogen in the Brazilian scenario based on a brief literature review.

Keywords
Green hydrogen; sustainability; Brazil; fuel; renewable energy sources

1. Introduction

Hydrogen is the most abundant chemical element in the universe, constituting approximately 90% of all atoms [1]. Although on planet Earth, its abundance is around 0.53 parts per million [2], hydrogen plays a significant role in various productive sectors, being required by the oil refining and petrochemical industries [3]. Its current use is justified by its excellent chemical versatility and high reactivity. Hydrogen is a lightweight gas with an extremely high calorific value [4]. It can be obtained through various synthesis routes, including alkaline water electrolysis [5-8]. However, conventional forms of H_2 production still predominate. These include methane reforming, catalytic decomposition of natural gas, partial oxidation of high-molecular-weight hydrocarbons, and coal or biomass gasification. In all these production forms, in addition to hydrogen as the final product, pollutants and greenhouse gas intensifiers (GHGs) such as CO_2, CO, NO_X, and CH_4 are commonly released [9].

Given the significant concern of global powers, such as the United States, Japan, China, and Canada, among others, regarding the consequences of greenhouse gas emissions (GHGs), there is an increasing trend toward proposing decarbonization measures for industrial processes. This aligns with the commitment outlined in the Agenda 2030, which encompasses 17 Sustainable Development Goals (SDGs), mainly focusing on the 13th goal. This goal emphasizes the need for urgent decision-making to combat global climate change and aligns with the sustainable development objectives established by the United Nations (UN) [9]. The Agenda 2030 is a worldwide action plan containing 17 Sustainable Development Goals with 169 associated targets involving different leaders that, in theory, commit to sustainable development [10].

The energy transition proposed by these countries aims to migrate and replace potentially polluting technologies and energy sources with sustainable systems that meet the growing global energy demand. One of the technologies mentioned is Power-to-Gas, which combines the water electrolysis stage with CO_2 methanation [11]. Among the goals outlined in the Agenda 2030 is the implementation of an energy transition that minimizes emissions related to greenhouse gases (GHGs), coupled with a reduction in energy dependence on sources subject to significant fluctuations in availability and costs. This transition also involves stimulating research and development of clean technologies, both within universities and by private initiatives, with the ultimate expectation of improving air quality [9, 12].

Like other nations, Brazil has been incorporating sustainable development policies in this context, including adopting green hydrogen as a clean and renewable energy source. Through a concise literature review, this article aims to examine the current Brazilian scenario regarding green hydrogen as a potential alternative fuel/energy source. It also provides a brief bibliographic analysis of research, development, and implementation of Brazilian green hydrogen technologies in academic works. Simultaneously, this article briefly addresses some crucial concepts and contextualizations related to the subject at hand.

2. Materials and Methods

In order to assess the main research conducted on the topic (green hydrogen), searches were carried out for academic documents available in the Scopus database. To do so, the search criteria included the period between the years 2014 to 2024, using the keyword "green hydrogen" associated with the term "Brazil". Bibliometric analysis was conducted with the support of the open-source software VOSViewer.

3. Results

Global governments have exerted several efforts towards the decarbonization of industrial processes. Since the international treaty known as the Paris Agreement in 2015, several countries committed to controlling greenhouse gas (GHG) emissions to limit the global temperature increase to below 2°C above pre-industrial levels. As a signatory to this treaty, Brazil has pledged to develop alternative, clean energy sources and decarbonize its industrial processes. These actions align with the commitments established by the Agenda 2030, aiming to promote sustainable development and enhance the atmospheric air quality for the next generations [13].

Green hydrogen has recently become a focal point of research interest in the country. Brazil leads research in the area of development and innovation in Latin America. Currently, the Hydrogen Laboratory of the Federal University of Rio de Janeiro (LABH2/COPPE) stands out, being a pioneer in research on the subject and having been active for over 35 years [14]. Given the increasing national energy demand, coupled with the rising emissions of atmospheric pollutants, green hydrogen emerges as a promising alternative fuel with notable cost-effectiveness, sustainability, non-toxicity, and only water as the final product after combustion [15]. The graph below, depicted in Figure 1, was generated from the Scopus virtual database platform, utilizing the keywords 'Green Hydrogen' and limiting the search to results published in Brazilian territory. There has been a significant growth in the number of published works in the country over the years, totaling 71 technical-scientific papers from 2014 to 2024. In 2023 the number of published works nearly doubled compared to the previous year, reaching a record peak (from 22 works in 2022 to 40 in 2023). These extracted data confirm that the national scientific community is increasingly interested in understanding and investing more in this subject. For instance, Petrobras, one of the largest oil and gas extraction and processing companies, has been investing resources into its energy transition, including the production of green hydrogen [16].

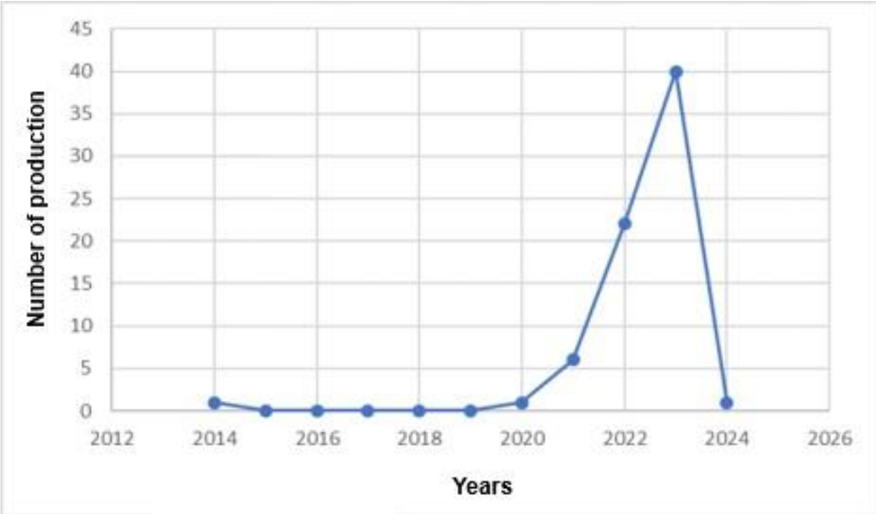

Figure 1 Scientific production of Green Hydrogen in Brazil from 2014 to 2024.

3.1 Hydrogen Production Color Palette

Hydrogen, in its natural form, is a colorless gas. However, depending on its different primary energy sources, the type of raw material consumed, and the potential pollutants generated and emitted during its production, it can be classified into nine different colors: brown, black, gray, blue, turquoise, white, pink, and, as the focus of this work, green hydrogen [17-19]. The following briefly describes the operations related to the respective hydrogen classification colors.

3.2 Black Hydrogen

Among the known hydrogen production technologies, the black classification is given to hydrogen generated from fossil sources, specifically coal. Black hydrogen is produced through the gasification of a type of coal called anthracite [18]. Black hydrogen becomes commercially attractive compared to other hydrogen production technologies due to its technological maturity and low operational cost [20].

Anthracite is a coal formed by metamorphism, a process involving changes in the mineralogical composition of pre-existing rocks through alterations in temperature, pressure, or composition. It can release a high amount of energy per kilogram and burn in a 'clean' manner, generating little soot. The gasification occurs when the carbon source is exposed to air or a mixture of water vapor and oxygen in high-temperature, high-pressure vessels. The elevated temperature and pressure lead to various reactions, producing a gas mixture containing hydrogen and carbon monoxide (CO). Subsequently, a steam reforming step is added, converting carbon monoxide into carbon dioxide (CO_2). This method of hydrogen production is widely used, given that coal is the fossil energy source with the largest reserves globally [21].

3.3 Brown Hydrogen

Similar to black hydrogen, brown hydrogen also employs a coal gasification process. However, the key difference lies in the type of coal used. In the case of brown hydrogen, lignite is utilized. Lignite, characterized by a substantial volatile matter content, facilitates its conversion into gas or petroleum products [19].

On the flip side, transportation and storage of lignite tend to be more challenging due to its high moisture content and susceptibility to spontaneous combustion. Another crucial point is that this type of coal generally emits more carbon dioxide (CO_2) than other coal types [19].

Hydrogen produced through brown and black classification sources is considered the least environmentally friendly due to the significant amount of CO_2 generated. Approximately 20 kg of CO_2 is estimated to be released for every kilogram of hydrogen produced. Even so, it is the most produced type of hydrogen in the USA [17].

3.4 Gray Hydrogen

The gray hydrogen production scale refers to hydrogen production through natural gas reforming without carbon capture, utilization, and storage. This methodology has the disadvantage of releasing high quantities of carbon dioxide [22]. Even though European countries are leading projects and initiatives to renew their energy matrix, substantial investments are still needed. Initial estimates indicate more than 430 billion euros, according to data from the European Commission on Energy Affairs [23].

This strategy is currently the most common and cost-effective, accounting for approximately 80% of the global hydrogen demand. Natural gas predominantly comprises methane (CH_4), and the reforming process begins with the gas undergoing pre-treatment to remove sulfur [21], as shown in Figure 2.

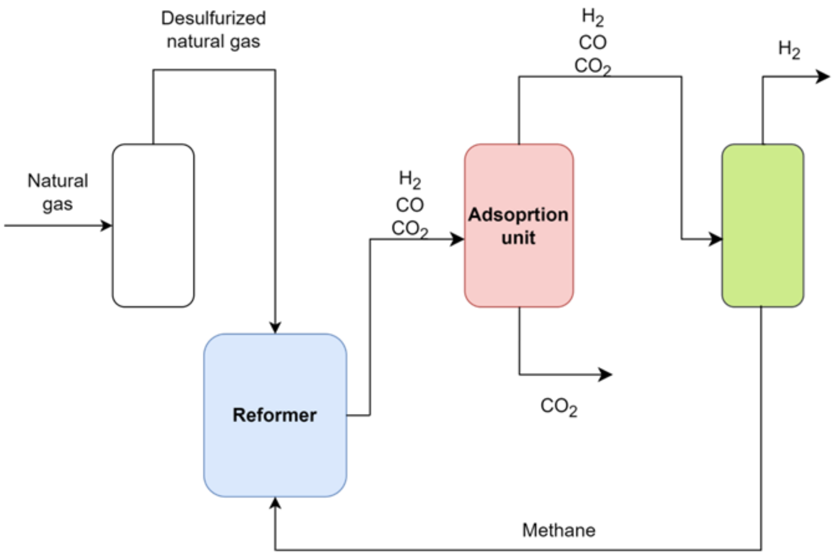

Figure 2 Gray hydrogen production scheme [24].

Next, a catalyst is added to the gas, reacting with water vapor. This reaction leads to the formation of hydrogen (H_2) and carbon monoxide (CO). However, due to the toxicity of CO, another catalyst is added, where carbon monoxide reacts with steam to form carbon dioxide (CO_2). This final step is exciting as it facilitates the gas separation stage, where the separated hydrogen is stored [25].

3.5 Blue Hydrogen

Blue hydrogen follows the same production process as gray hydrogen, i.e., by reforming fossil fuels; however, it incorporates a carbon capture, utilization, and storage (CCUS) stage. It is important to note that CCUS is not without environmental challenges, and consequently, the energy source used in blue hydrogen production cannot be considered clean [21]. It is also worth highlighting that the increase in carbon prices in the international market is expected to drive CCUS projects, as carbon capture becomes more attractive when a significant added value is associated [26].

3.6 Pink Hydrogen

Hydrogen is produced through water electrolysis using energy generated in nuclear reactors [17]. Among the elements that can be used to obtain nuclear energy, uranium stands out due to its abundant reserves. However, uranium is still a finite resource and does not qualify as a renewable source for pink hydrogen production [21]. Another relevant point is that, despite not generating polluting gases, the radioactive waste produced in nuclear reactors is highly harmful to the environment. Additionally, the operation of a nuclear power plant carries considerable risks for the region it occupies.

3.7 Turquoise Hydrogen

The turquoise classification within the hydrogen production rainbow refers to emissions-free production. In other words, turquoise hydrogen is produced through the pyrolysis of methane from natural gas. This endothermic reaction requires an energy source to convert methane into hydrogen gas and solid carbon [25]. However, it is essential to emphasize that this energy source must be free of CO_2 emissions for the hydrogen to be considered turquoise [25].

The pyrolysis of methane occurs in a reactor, resulting in solid carbon and hydrogen. Subsequently, the hydrogen is collected in gas form, and the carbon is removed from the bottom [25]. It is noteworthy that turquoise hydrogen has added value due to the production of solid carbon, which has various applications [27].

3.8 White Hydrogen

White hydrogen refers to hydrogen found in its natural form, obtained through the extraction of gas from geological sources such as the bottom of oceanic crusts, volcanic gases, hydrothermal systems, etc. White hydrogen arises from various natural sources such as bacterial activity, natural electrolysis, iron oxidation in sedimentary basins, etc. [17]. Despite being a source free of emissions harmful to the environment, there are not many plans for the exploration of white hydrogen due to the fact that those from other sources prove to be much more advantageous [21].

3.9 Hydrogen from Biomass

Hydrogen from biomass is obtained through catalytic reforming, processes of gasification of residual plastics, or anaerobic biomass digestion with or without CCUS [22]. Research associated with this technological pathway has been growing due to the demand for more sustainable industrial processes aimed at waste reduction [19]. Biological pathways generally emit low levels of carbon and sulfur compounds [28].

The biomass gasification process is carried out in four stages: biomass drying, pyrolysis to initiate its decomposition, combustion of the obtained product, and material reduction. Carbon monoxide

(CO) and hydrogen gas (H_2) are formed in this last stage. Finally, the generated carbon monoxide can still be converted into CO_2 [21].

3.10 Green Hydrogen

This classification is given to hydrogen produced from water electrolysis using energy generated from renewable sources [22]. Among the existing production alternatives, this method stands out for being free from greenhouse gas emissions, the so-called GHGs.

Electrolysis involves an electrochemical method where, in devices called electrolyzers, an electric current passes through, generating a flow of electrons between electrodes immersed in an aqueous solution [22]. This methodology is considered the most efficient in water splitting [29], i.e., breaking down water molecules and promoting their decomposition into their elements [30]. The energy required for this separation process can come from various sources, including thermal, electromagnetic radiation, or, in the case of electrolysis, electrical [30].

The water electrolysis process has a base reaction where one mole of water produces one mole of hydrogen gas and half a mole of oxygen gas, as shown below [15]:

$$H_2O + Electricity \rightarrow H_2 + \frac{1}{2}O_2 + Heat$$

Electrolysis is a well-established and widely publicized technique. Currently, the most commonly used technologies are alkaline electrolysis, proton exchange membrane (PEM) electrolysis, and solid oxide electrolysis cells (SOEC) [29]. Figure 3 illustrates the process of water electrolysis.

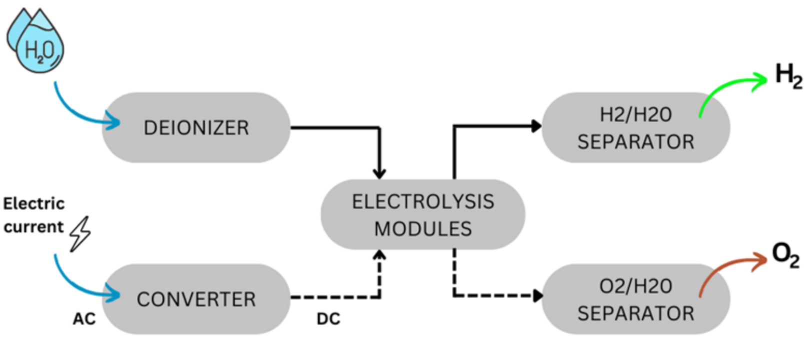

Figure 3 Diagram of the water electrolysis process [29].

In the case of alkaline electrolysis and SOEC, water is introduced at the cathode, where it is split, generating H_2 and OH^- ions. The synthesized hydroxide ions are soluble in the aqueous phase and move toward the anode, where oxygen gas (O_2) forms. At the process's end, hydrogen and the formed oxygen are separated in external systems. The difference between alkaline electrolysis and the SOEC system is that the latter uses thermal energy, while the former uses electrical energy [29].

Reaction at the anode (alkaline and SOEC):

$$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$$

Reaction at the cathode (alkaline and SOEC):

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2$$

On the other hand, in the proton exchange membrane (PEM), water is introduced on the anode side, where it is split into H^+ ions that pass through the membrane, reaching the cathode to generate H_2 and O_2 gas, which remains in the liquid phase [29, 31].

Reaction at the anode (PEM):

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

Reaction at the cathode (PEM):

$$4H^+ + 4e^- \rightarrow 2H_2$$

Despite being very interesting, electrolysis results in high electricity consumption, making competing with other large-scale technologies challenging. However, if the electricity used is supplied by renewable energy sources such as wind, solar, and hydropower, the produced hydrogen becomes the cleanest energy carrier. It can be used to store excess electrical energy and enhance the efficiency of the plant on a smaller scale [29].

3.11 Applications of Green Hydrogen in Brazil

Brazil has been increasing its interest in the development of hydrogen utilization within the country. Much of this interest is due to incentives from the World Bank Group, which aims to establish green hydrogen as an energy alternative in this country and others (India, Chile, China, Germany, Japan, and Australia) [19].

In 2002, the Ministry of Science and Technology launched the Brazilian Program for Fuel Cell Systems (PROCAC), renamed in 2005 to the "Science, Technology, and Innovation Program for the Hydrogen Economy (ProH2)." The same year, the Ministry of Mines and Energy coordinated the "Roadmap for Structuring the Hydrogen Economy in Brazil," which involved a comprehensive study in collaboration with the Ministry of Science and Technology and various national and international experts, companies, institutes, and research centers. The study covered the following topics [32]:

- ✓ Foundations for the Development of the Hydrogen Market.
- ✓ Hydrogen Production.
- ✓ Hydrogen Logistics.
- ✓ Conversion Systems.
- ✓ Applications of Hydrogen as an Energy Vector.
- ✓ Technological Development and Human Resources Training.
- ✓ Metrology, Standardization, Technical Regulation, Conformity Assessment, Regulation, and Supervision.

This roadmap highlights some important information:

- ✓ Valuation of different technological routes in which Brazil could have competitive advantages, such as: ethanol (not only through reforming but also through direct oxidation in fuel cells), water electrolysis (using secondary electricity from hydropower plants), and other biomasses, in addition to sugarcane, including biogas.
- ✓ Recognition of natural gas's role in facilitating the transition to a phase dominated by green hydrogen.

- ✓ Definition of a market diffusion logic for hydrogen: distributed energy generation, energy production in isolated regions, and urban buses.
- ✓ The technical document established a 20-year schedule from 2007 to achieve goals related to hydrogen production and incorporation into the economy. It anticipated the launch of a Government Program for Hydrogen Production and Use in Brazil after this date. However, with the discovery of pre-salt reserves in 2006, priorities regarding energy policies were reconsidered, and the planned government program was not implemented, although some projects related to hydrogen production in the country are still maintained.

Some of these projects, resulting from collaborations between universities, research institutes, and companies, include:

- Itaipu Binacional, in partnership with the Federal University of Paraná (UFPR) through the Brazilian Center of Reference on Biofuels (CERBIO).
- Institute of Energy and Nuclear Research in collaboration with the Center for Research in Electric Energy (CEPEL) of Eletrobras, Institute of Technological Research (IPT), and the University of the State of São Paulo (UNESP).
- Coordination of the Graduate Programs in Engineering at the Federal University of Rio de Janeiro (COPPE/UFRJ), which houses the Hydrogen Laboratory and the Hydrogen Technology Reference Center, in partnership with CEPEL/Eletrobras.
- Implementation of a Bus Fleet in the City of Rio de Janeiro supported by FINEP (Brazilian Funding Agency for Research and Development), Petrobras (Brazilian state-owned petroleum company), National Council for Scientific and Technological Development (CNPq), and Research Support Foundation of the State of Rio de Janeiro (FAPERJ) [14].

A significant portion of the demand for hydrogen in the country comes from the chemical and petroleum sectors, especially in catalytic hydrocracking processes of hydrocarbons and ammonia production for fertilizer manufacturing [4].

In the mining sector, there is a significant demand for energy to operate large-scale equipment, typically met by diesel oil. Equipment powered by diesel is often more adaptable to adverse terrains and is more commonly found. However, the work of Figueiredo and colleagues [33] analyzes the possibility of decarbonizing the mining industry by using green hydrogen as an alternative. This study highlights concerns related to the use and dependence on diesel as a fuel responsible for emitting large amounts of CO_2 into the atmosphere through combustion. However, according to the author, the introduction of hydrogen into the sector through the "hydrogen economy" must overcome some obstacles, including:

- ✓ Dissemination of hydrogen: This involves reducing costs associated with its production, as there is a demand for electrical energy during electrolysis, and likewise, expenses related to its storage, as it needs to be pressurized or cryogenically stored to remain in a liquid state.
- ✓ Integration with the electrical grid: The hydrogen production system should be integrated with the electrical grid so that renewable energy sources such as solar, wind, and hydropower can power the plant.
- ✓ Infrastructure development: The country's necessary infrastructure for installation, transportation, and storage is not fully matured.
- ✓ Limited incentives for research and projects: There is a lack of sufficient incentives for developing research and projects to incorporate the "hydrogen economy" into industries.

Faro *et al.* [34] noted that Brazil still has significant challenges in adopting even a partial hydrogen-based energy matrix. Specific sectors like cement, mining, and steel production resist the transition.

Achieving the goal of establishing hydrogen industrial plants in Brazil requires a collaborative effort among development banks (such as BNDES), research agencies (like CNPq), universities, regulatory agencies (including ANEEL and ANP), and standardization bodies (such as ABNT) [35].

3.12 Academic Research on Green Hydrogen Production

With the increasing demand for green hydrogen as a sustainable energy source, there is a growing need for investment from the academic community in research focused on synthesizing this fuel through financially and environmentally viable processes. Brazil's progress in green hydrogen research and development owes much to government funding sources. FINEP (The Brazilian Financier of Studies and Projects) is the main one. Operating nationwide, FINEP supports laboratory infrastructure and technology park implementation projects. In addition, there are other local financial support agencies. However, their actions are regional and directed to the States.

With the assistance of the free software VOSviewer, bibliometric analysis can be conducted by constructing and visualizing maps based on bibliometric networks. The map presented in Figure 4 below allows for examining the most frequently associated keywords with the term "Green Hydrogen" when using the Scopus scientific database, limited to articles published in Brazil. Bibliometric analysis quantitatively assesses scientific production, highlighting influential researchers and institutions in a particular field.

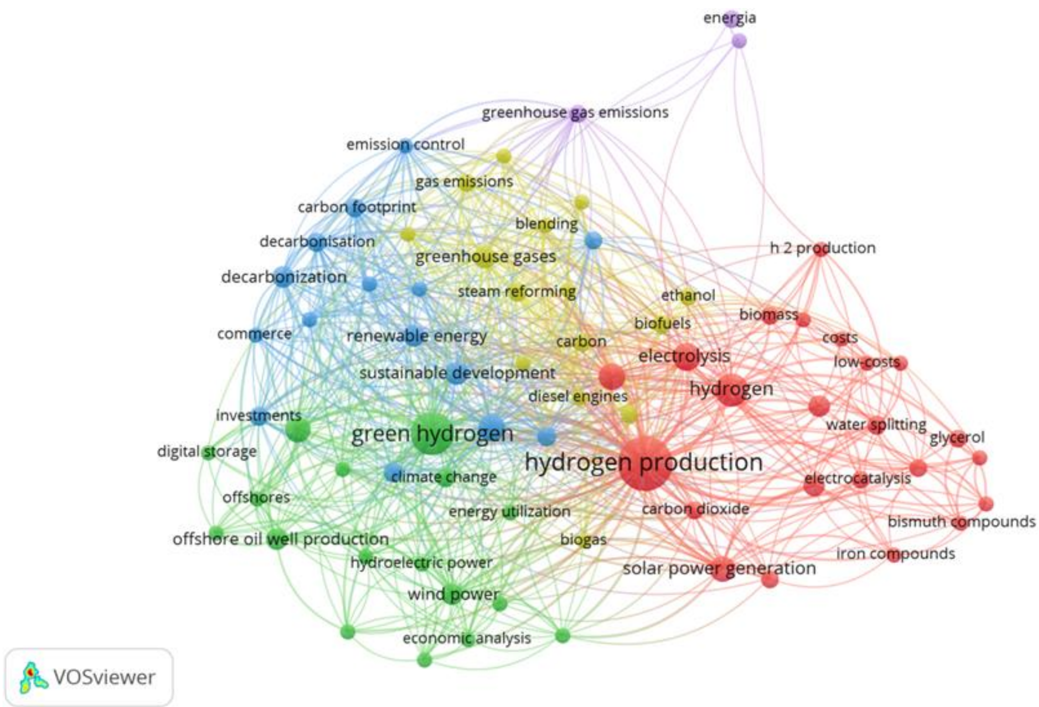

Figure 4 Bibliometric map generated within the VOSviewer software from data related to the keyword "Green Hydrogen" extracted from the Scopus database in national scientific productions.

The VOS viewer uses the Visualization of Similarities (VOS) method to define network nodes and connections. Based on two-dimensional visualizations created by this tool, objects with high similarity are closer. Thus, keywords that are closer to each other have a greater tendency to be cited in the same production [36]. In Figure 4, generated from keyword co-occurrence, the term "green hydrogen" within national publications is closely related and commonly cited alongside the terms "sustainable development," "climate change," and "hydrogen production." The latter term is frequent, indicating that Brazilian works aim to develop ways to produce green hydrogen through various methodologies. In total, 73 keywords related to scientific productions on green hydrogen were identified, divided into 5 clusters of multiple colors.

Within the topic, some academic papers have been investigating ways to optimize and facilitate the occurrence of the water-splitting reaction for obtaining hydrogen at a low cost and clean manner. In the work of Silva and collaborators [37], various manganese oxides (MgO) were tested as catalysts for the Water Oxidation Reaction (WOR). According to the authors, the reaction associated with this step is the most demanding, thermodynamically and kinetically. The use of manganese oxides is explored considering their presence, in the form of Mn_4CaO_5, in photosynthetic organisms as natural catalysts for WOR, in addition to having the presence of Mg as an abundant and low-cost transition metal compared to precious metals and more expensive metallic oxides.

$$2\mathrm{H_2O} \rightarrow 2\mathrm{H_2} + \mathrm{O_2} \qquad (\mathrm{Eq.\,1} - \text{water splitting reaction})$$

$$2\mathrm{H_2O} \rightarrow \mathrm{O_2} + 4\mathrm{H^+} + 4\mathrm{e} \qquad (\mathrm{Eq.\,2} - \text{water oxidation reaction/WOR})$$

Within this work, the authors worked with three different types of crystal structures of manganese oxide, namely α-MnO_2, σ-MnO_2, α,γ-MnO_2, and Mn_2O_3, which were treated with organic compounds to promote the reduction of manganese from the Mn(IV) state to Mn(III) and enhance the progress of the Water Oxidation Reaction (WOR). In summary, oxides with the presence of Mn(IV), α-MnO_2, σ-MnO_2, α, and γ-MnO_2 showed favorable catalytic activity, while the Mn(III) oxide, Mn_2O_3, showed a decrease in its activity [37].

Regarding the evaluation of other varieties of oxides for use as catalysts in the Water Oxidation Reaction (WOR), the work of Cordeiro and Carvalho [38] employs cobalt oxide, Co_3O_4, also treated with organic compounds for the stabilization of the chemical species Co(III) by the adsorption of organic molecules. The synthesized catalysts can be reused up to five times before their catalytic activity significantly decreases [38].

3.13 Outlook for the Evolution of Green Hydrogen in Brazil

On December 16, 2020, the Ministry of Mines and Energy (MME) approved the National Energy Plan (PNE) for 2050. Developed by the Energy Research Company (EPE), the plan serves as a tool to support the design of the long-term strategy for the expansion of the energy sector in the country. This plan presents a set of recommendations and guidelines to be followed until 2050. The strategy is based on four main pillars: energy security, adequate return on investments, availability of access for the population, and socio-environmental criteria [32, 39].

Within the PNE, hydrogen is included as a disruptive technology and recognized as an element of interest in decarbonizing the Brazilian energy matrix. Regarding introducing electric vehicles in the transportation sector, the PNE 2050 points to the technological perspective of using fuel cells, with hydrogen produced from liquid biofuels, natural gas, or biomethane [32, 39].

Another aspect considered in the PNE 2050 is the possibility of blending hydrogen into natural gas networks, in specific percentages and at limited pressures, for transportation and storage purposes. This is seen as an effective way to optimize existing infrastructure and provide significant volumes of hydrogen for energy purposes [39].

In the context of the decarbonization process and hydrogen integration, the PNE 2050 highlights some recommendations for energy policy, including [39]:

- ✓ Encourage opportunities provided by hydrogen use to decarbonize critical sectors such as industry (oil refining, petrochemicals, chemicals, steel production, etc.) and transportation, among others.
- ✓ Design regulatory enhancements related to quality, safety, transportation infrastructure, storage, and supply, as well as encourage and promote the adoption of new technologies.
- ✓ Coordinate initiatives in collaboration with international institutions in the field of hydrogen.

In 2021, the Electric Power Research Center (CEPEL) made available on its website a calculator for the cost of green hydrogen production through electrolysis. Using an online application, users can calculate the Levelized Cost of Hydrogen (LCOH), an internationally recognized parameter for assessing the economic feasibility of green hydrogen plants. Through an intuitive and accessible interface, users can utilize this parameter to evaluate the financial viability of green hydrogen production plants and compare their production costs with plants using other resources, such as natural gas [40]. The Research Center has been at the forefront of developing technologies related to green hydrogen, contributing to projects related to green hydrogen development in collaboration with CEPEL partners.

LCOH is an international metric to assess the cost of hydrogen produced in a specific facility or project. This metric considers various factors such as capital costs, operational costs, the efficiency of the hydrogen production process, and the project's lifespan. Therefore, preliminary economic viability analyses of a green hydrogen plant can be conducted, comparing it with the cost of hydrogen obtained from other energy sources [40, 41].

4. Conclusions

This analysis of the role of green hydrogen in the Brazilian context reveals a promising perspective for energy transition and the pursuit of sustainable solutions. A brief literature review highlighted the most relevant topics, including the contextualization of hydrogen types, focusing on the green route as an explored alternative in the national territory. An increasing number of scientific and academic works have been produced over the years aiming to optimize hydrogen production through more superficial and less costly routes. However, its full implementation remains challenging as a substitute for current hydrogen synthesis routes. The search for more efficient and economical hydrogen production methods is crucial to drive the adoption of hydrogen as a sustainable energy source in various sectors, such as transportation, industry, and power generation. In Brazil, the involvement of funding sources from agencies like FINEP is crucial to drive green hydrogen research and promote the implementation of technology parks. The recently approved legal framework for green hydrogen in Brazil establishes rules and benefits to stimulate the production and supply of this fuel. Adopting policies and legislation such as the PNE, combined with the increase in the national fleet of electric vehicles, could boost research on hydrogen production in Brazil. This research, still in its early stages in the country, represents only 0.6% of Brazilian articles published on the subject and available on the ScienceDirect platform. However, investments in research and development must be made. Without them, the country may miss the opportunity to become one of the major players in the energy transition, losing out on opportunities and investments.

Author Contributions

Marco was responsible for the initial draft of the manuscript, Luiza and Rômulo were responsible for data collection and processing, Marco and Harrison performed the translation and final manuscript review.

Competing Interests

The authors declare that there are no conflicts of interest.

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