BRAZILIAN HYDROGEN ECONOMY DEVELOPMENT

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ABSTRACT

Hydrogen is being seen as an essential factor in the success of the energy transition. This paper aims to evaluate the status of the hydrogen economy in Brazil and provide strategies for promoting its development. An adapted SWOT and GUT analysis of the Brazilian hydrogen economy is performed and used to identify and prioritize strategies to fully utilise the strengths and opportunities, avoiding or mitigating the weaknesses and threats. The main results of the analysis are the strong potential of renewables and its competitiveness in the Brazilian matrix. The main weakness is the costs of the entire green hydrogen production chain to take advantage of this renewable potential. Another issue is that Brazil is not showing signs of implementing a clear hydrogen strategy, losing the world investment time in Latin America. Since countries like Chile and Colombia already have their strategies ready, giving positive signals to investors.

Keywords: Hydrogen economy; SWOT analysis; GUT analysis; Hydrogen strategy; Brazil.

RESUMO

O hidrogênio está sendo visto como um fator essencial para o sucesso da transição energética. Este trabalho tem como objetivo avaliar a situação da economia do hidrogênio no Brasil e fornecer estratégias para promover o seu desenvolvimento. Análises SWOT e GUT da economia brasileira de hidrogênio foram realizadas de forma adaptada e usadas para identificar e priorizar estratégias para utilizar plenamente pontos fortes e oportunidades, evitando ou mitigando pontos fracos e ameaças. Os principais resultados da análise são o forte potencial das renováveis e sua competitividade na matriz brasileira. A principal fra-

queza são os custos de toda a cadeia produtiva do hidrogênio verde para aproveitar esse potencial renovável. Outra questão é que o Brasil não dá sinais de implementação de uma estratégia clara para o hidrogênio, perdendo o tempo de investimento mundial na América Latina. Países como Chile e Colômbia já têm suas estratégias prontas, dando sinais positivos aos investidores.

Palavras-chave: Economia de hidrogênio; Análise SWOT, Análise GUT, Estratégia de hidrogênio; Brasil.

1. INTRODUCTION

Hydrogen is an important factor in the energy transition's success in achieving carbon-neutrality in sectors difficult to decarbonise (KAKOULAKI et al., 2021). Hydrogen's high mass-energy density, lightweight, and easy electrochemical conversion allow it to carry energy across geographical regions through pipelines or liquid fuels like ammonia on freight ships. Across sectors, it can be used as a chemical feedstock, burned for heat, used as a reagent for synthetic fuel production, or converted back to electricity through fuel cells. Furthermore, hydrogen's long-term energy storage capacity in tanks or underground caverns makes it a technology that can store energy across seasons. This drove many prominent scientists and economists to suggest a future in which gas will be the leading solution in the battle against climate change (OLIVEIRA; BESWICK; YAN, 2021).

The concept of the hydrogen economy was coined in 1972. Still, in recent years, the cost of its complete value chain has dropped sufficiently so hydrogen can be deployed commercially. The major factors driving the change in the costs of the hydrogen value chain include: (i) the dramatic fall in the cost of solar and wind electricity and, (ii) the steady improvement in the commercial status of electrolysers, fuel cells and supporting infrastructure (BURDON; DR PALMER; DR CHAKRABORTY, 2019).

The studies carried out by (DAWOOD; ANDA; SHAFIULLAH, 2020) show that the hydrogen economy has been actively investigated; many reviews and case studies have been prepared as well, as many roadmap reports were published highlighting key progress made and the role of hydrogen within the energy sector. There is a growing interest in making the production and utilisation of hydrogen a more scalable and versatile process. If the global demand for hydrogen increases as a result, then it is likely that a global hydrogen market will emerge to satisfy that demand (MILANI; KIANI; MCNAUGHTON, 2020). According to Astute Analytica, The Global Hydrogen Market is estimated to witness a rise in revenue from US$ 206.6 billion in 2022 to US$ 761.3 billion by 2040 (ASTUTE ANALYTICA, 2023).

The production from steam reforming of natural gas and industrial uses of hydrogen in Brazil are relatively consolidated (DA SILVA CÉSAR et al., 2019; MME, 2021a). However, the broader use of hydrogen-based energy projects will require continued research, development and innovation investment allowing the country to become a relevant actor in the Hydrogen Economy (MME, 2021a). According to (CHAVES; DORES; DE CASTRO, 2021; MCKINSEY&COMPANY, 2022), Brazilian renewable power potential is one of the greatest globally, which can drive the country to be a leader in the green hydrogen market. However, green hydrogen production is highly expensive, as it uses technologies that are still emerging in the market and do not have scale production (IEA, 2019). Therefore, the hydrogen production chain must be deployed competitively to contribute to the expansion of this market as a whole (DA SILVA CÉSAR et al., 2019).

Hence, this work aims to evaluate the status of the hydrogen economy in Brazil and provide strategies for promoting its development. A SWOT analysis is used to identify the strengths, weaknesses, opportunities and threats of building a hydrogen economy in Brazil. Under this vision, this study seeks to answer whether Brazil could develop a solid hydrogen economy.

This paper consists of three parts: (i) an overview of hydrogen´s role in Brazil, bringing up features about production and infrastructure, the technology used, regulation, market and consumption; (ii) an adapted SWOT and GUT analysis of the Brazilian hydrogen economy is performed. The SWOT and GUT matrix identify and prioritize strategies to fully use the strengths and opportunities, avoiding or mitigating the weaknesses and threats; (iii) conclusion, given an overview of the abovementioned matters.

2. OVERVIEW OF HYDROGEN IN BRAZIL

Currently, there are norms applied to the production of hydrogen for medical use, the transport of hazardous products, and technical norms for its storage (MAUR; LEITE; SCH, 2021). However, there is no specific rule from the Brazilian Electricity Regulatory Agency (ANEEL) or the Brazilian Regulatory Agency for Petroleum, Natural Gas and Biofuels (ANP) that regulates the production, storage and transport of hydrogen for energy uses or for the hydrogen market (EPE, 2021a; MAUR; LEITE; SCH, 2021). However, Brazil has been establishing bases for its hydrogen strategy since 2002, and in 2021 the Brazilian Energy Policy Council (CNPE) launched the National Hydrogen Program (EPE, 2021b; PEYERL, 2018). Brazil is a leader in Research, Development and Innovation (RD&I) in hydrogen technologies in Latin America (BRASIL-ALEMANHA, 2021). Several research groups in uni-

versities maintain laboratories of high international standards to develop technologies applicable to the national reality. Brazil also presents some national projects in green hydrogen, as pointed out in (BRASIL-ALEMANHA, 2021).

Green hydrogen is costly across its entire value chain, from electrolysis to transport and fuel cells. The insufficient infrastructure for transport and storage, the high energy losses and the lack of value for the primary benefit (e.g. lower Green House Gas emissions) that green hydrogen can have contribute substantially towards the high costs (TAIBI et al., 2020).

Electricity input is the major cost of green hydrogen production, and electrolysers' efficiency and capital cost are second (IEA, 2019; LONGDEN et al., 2020). Brazil's solar and wind power potential will likely foster a strong hydrogen market (CHAVES; DORES; DE CASTRO, 2021; MACEDO; PEYERL, 2022). Besides, another option for Brazil to make green hydrogen production feasible is using spillage from hydropower plants (a portion of water diverted to the spillway, that is, wasted) (NADALETI; BORGES DOS SANTOS; LOURENÇO, 2019). Brazil has demonstration projects of hydrogen production by electrolysis in the hydroelectric power plants of Itaipu, Itumbiara and Porto Primavera (MME/EPE, 2020).

Brazil's 2050 National Energy Plan outlines that electrolysers would be produced in the country as an alternative to reduce costs by nationalising the supply chain (MME/EPE, 2020). The electrodes are based on nickel alloys when considering alkaline electrolysis, a raw material abundant in Brazil. That could be a starting point for the electrolysers manufactured in Brazil to become price-competitive (MME/EPE, 2020).

Natural hydrogen sources may also represent a new attractive primary carbon-free energy resource. The São Francisco Basin, located in the Brazilian states of Minas Gerais and Bahia, belongs to a shortlist of intracratonic basins where hydrogen seepages have been discovered (DONZÉ et al., 2020; MME/EPE, 2020). Another abundant energy source in the country is biomass, according to the Brazilian Electricity Grid Operator (ONS), which currently accounts for 8,3% of the Brazilian supply mix (installed capacity) (ONS, 2021). Apart from water electrolyzes, producing hydrogen by ethanol reform and biomass gasification was also part of the Road Map for the Structuring of the Hydrogen Economy in Brazil and the Science, Technology and Innovation Program for the Hydrogen Economy (ProH2) (AHK, 2019; ZACHARIAS; MACEDO; PEYERL, 2022).

On the scope of hydrogen storage and transportation, costs are also critical. Hydrogen is usually stored and transported in compressed or liquified gas due to its low density (MAYYAS; WEI; LEVIS, 2020). Also,

storage can be carried out in salt caves and depleted gas or oil reservoirs, enabling large-scale and long-term storage with lower costs than tanks (ELIZIÁRIO et al., 2020). Transmission and distribution can also be done through hydrogen blends in the natural gas pipelines (ELIZIÁRIO et al., 2020). Some countries have already instituted limits on hydrogen blending in natural gas networks. Germany ranges from 2% to 8% depending on certain conditions, France 6%, Spain 5%, and Australia 4% (IEA, 2020).

As claimed by PNE 2050, it is highly recommended to evaluate the barriers related to transport, storage and supply infrastructure to define the necessary regulatory improvements, such as the regulation of the mixture of hydrogen with natural gas in the natural gas network, which would minimize the need to build infrastructure and associated costs (MME/EPE, 2020). In 2022, Bill 725 was presented, considering the addition of hydrogen in the natural gas transport pipelines following mandatory minimum percentages in the volume of 5% in 2032 and 10% in 2050 (SENADO FEDERAL, 2022). Regarding the geological storage of hydrogen, PNE 2050 brings up that these issues can be set on the scope of the definition of the regulatory framework for the storage of natural gas (MME/EPE, 2020).

According to (MME; EPE, 2022a) there is considerable production and consumption of hydrogen in Brazil through the grey hydrogen route. The technical paper launched by (MME; EPE, 2022c), points out that the production of hydrogen in Brazilian refineries in the last two years has remained at an average of nearly 300,000 t/year, and it is expected to reach approximately 400,000 t/year by 2030. Currently, the primary purpose of hydrogen production is its use in refineries for hydrotreatment processes of gasoline, diesel and lubricants, aiming at the adequacy of the quality of these products (BRASIL-ALEMANHA, 2021; MME; EPE, 2022c). Up to 2019, hydrogen was used in fertilizers production, which ended with hibernation and leasing of the units (BRASIL-ALEMANHA, 2021). According to (BRASIL-ALEMANHA, 2021), 95% of hydrogen production in Brazil comes from Petrobras, and the remaining 5% is produced by companies that supply industrial gases in the country, such as Air Liquide, Linde, Air Products and Masser, represented by White Martins.

3. DEVELOPMENT OF ADAPTED SWOT AND GUT ANALYSIS

Strengths–weaknesses–opportunities–threats (SWOT) analytical method is widely used for strategy formulation by constituting an essential basis for learning about the situation of the studied object and for designing future strategies to solve the existing problems (REN et

al., 2015). Therefore, SWOT analysis is used in this paper to identify these features in the Brazilian hydrogen economy and subsequently evaluate strategies for promoting its development by exerting strengths, mitigating weaknesses, exploiting opportunities and avoiding threats.

The prioritization matrix GUT is a tool widely used by companies to prioritize problems to be tackled, as well as to analyse the priority in which certain activities must be performed considering three dimensions: gravity, urgency and tendency (CLEGINALDO PEREIRA DE CARVALHO; CAROLINE FERREIRA DE CASTRO, 2020). This work combines the GUT matrix with the SWOT analysis to identify and prioritize decision-making processes that enhance competitiveness for developing a hydrogen economy in Brazil.

Thus, this analysis was carried out based on (AREND, 2021), considering the following methodological steps:

i. Literature review is built on reports released by the Brazilian government and complemented by reports issued by private educational and research institutions directly related to the hydrogen economy in Brazil.

ii. Conducting a SWOT analysis to identify the main points about the Federal Government's vision related to the hydrogen economy and provide strategies for promoting its development.

iii. Conducting a GUT analysis to define priorities given alternatives of action to prioritize problems and treat them. This work adopts the GUT method to consider only the urgency dimension.

Therefore, it was considered to analyse the materials published from December 2020 to December 2022. This period is justified due to the publication of the National Energy Plan 2050 (PNE 2050) on December 2020, pointing for the first time to hydrogen as a disruptive technology and as an element of interest in decarbonising the energy matrix (MME/EPE, 2020). Thus, this chapter intends to evaluate the developments of hydrogen in Brazil up to the present moment.

3.1 Performing the SWOT analysis

To perform the SWOT analysis, 22 reports were selected from the literature review presented in Table 1. The SWOT matrix was built based on (AREND, 2021) by evaluating the reports, according to Tables 2 and 3.

Table 1 - Literature review

Title	Year	Author
Plano Nacional de Energia 2050	2020	MME/EPE
Novas perspectivas para o mercado de hidrogênio com o novo mercado de gás	2020	GESEL
Bases para a consolidação da estratégia brasileira do hidrogênio - No EPE-DEA-NT-003/2021	2021	MME/EPE
Programa Nacional do Hidrogênio	2021	MME/EPE
Resolução nº2/2021 do CNPE	2021	CNPE
Resolução nº6/2021 do CNPE	2021	CNPE
O Brasil na Transição Energética para o Hidrogênio Verde	2021	GESEL
O papel estratégico do hidrogênio verde na transição energética global	2021	GESEL
Perspectivas da Economia do Hidrogênio no Setor Energético Brasileiro	2021	GESEL
Contextos e Estratégias do Programa Nacional de Hidrogênio do Brasil	2021	GESEL
Mapeamento do Setor de Hidrogênio Brasileiro	2021	German-Brazilian Energy Partnership
Hidrogênio Cinza: Produção a partir da reforma a vapor do gás natural	2022	MME/EPE
Hidrogênio Azul: Produção a partir da reforma do gás natural com CCUS	2022	UK Government/ MME/EPE
Hidrogênio Turquesa: Produção a partir da pirólise do gás natural	2022	UK Government/ MME/EPE
Produção e Consumo de Hidrogênio em Refinarias no Brasil	2022	MME/EPE
PDE 2031	2022	EPE/MME
Hidrogênio Sustentável - Perspectivas e Potencial para a Industria Brasileira	2022	CNI
Panorama do Hidrogênio no Brasil	2022	IPEA
Projeto de Lei n° 1878/2022	2022	CMA – Senado Federal
Projeto de Lei nº 725/2022 - Lei do Hidrogênio	2022	Senador Jean Paul Prates - Senado Federal
Consulta Pública MME nº 147 de 14/12/2022 - Plano de Trabalho Trienal do Programa Nacional do Hidrogênio (2023-2025)	2022	MME
Manual para Certificação de Hidrogênio	2022	CCEE

Table 2 - SWOT Matrix, Strengths and Weaknesses

Strengths	Weaknesses
a. Publication of two resolutions with positive implications for the development of hydrogen in the country. The first of them, CNPE Resolution No. 2 of 2021, guides the prioritization of the allocation of research, development and innovation resources regulated by ANEEL and by ANP for hydrogen, among other topics related to the energy sector and the energy transition. The second, CNPE Resolution No. 6 of 2021, deals with the determination to propose guidelines for the National Hydrogen Program (PNH2). b. In 2021, the MME of Brazil launched the PNH2 to define a set of actions that facilitate the development of three fundamental pillars for a successful hydrogen economy: public policies, technology and market. c. The activities carried out within the scope of the PNH2 throughout 2022 resulted in the elaboration of the Triennial Work Plan 2023-2025. This plan aims to guide the federal government's actions in developing the hydrogen sector in the coming three years. d. ABNT has been discussing the regulation of hydrogen technologies, from production to end use, within the scope of the Special Study Commission on Hydrogen Technologies – ABNT/CEE-067. e. Brazil has some relevant investments in R&D of hydrogen production in several technological routes: renewable (ethanol, hydro, wind, solar and biomethane) and natural gas. f. Brazil has demonstration projects using hydrogen technology in buses and ships as well as the production of hydrogen by water electrolysis at the Itaipu, Itumbiara and Porto Primavera hydroelectric plants, in addition to steam reformers from natural gas and ethanol, including business activities. g. The production and industrial uses of grey hydrogen in Brazil are relatively consolidated. h. Initiatives of international partnerships and projects aimed at accelerating the formalization of the national hydrogen strategy. The Brazil-Germany Chamber of Commerce and Industry (AHK) is a good example. i. Given the significant competitiveness of variable renewables (wind and solar) in Brazil, particular interest in the development of green hydrogen in the country by foreign partners (especially Germany) and national and international entrepreneurs. j. The country also has companies that already operate in the hydrogen market and an association that brings together companies in the sector and other interested parties (ABH2). k. Potential of diversified energy resources available, from water, wind, solar, biofuels and biomass sources, including natural gas, the main input in the production of hydrogen in the world. l. Electricity transport infrastructure. m. Brazil has an institutional structure that includes an energy policy with long-term planning (EPE), centralized operation of the electrical system (ONS) that meets the load spatially dispersed in the Brazilian territory, a consistent and independent regulatory framework (ANEEL), an efficient contract compensation system (CCEE) and consolidated financing standard for renewables (BNDES). Ease production flow due to the extension of the coast. n. Hydrogen certification, launched in 2022 by CCEE, for hydrogen production via electrolysis.	a. Institutional, legal and regulatory structures must be improved, adapting them to provide stability, predictability and confidence to investors. It will also be necessary to provide security for the industry and consumers. b. Petroleum refining is an important producer of hydrogen in the country, but this production is used for internal consumption in refineries, and there is no market for this product. As a result, production is equal to the consumption of the refineries, with idle productive capacity available for eventual needs in the hydrogen markets. c. Despite the traditional Brazilian fertilizer market and its use in refining processes, other applications of H2 have not been stimulated to generate an additional competitive market. d. There are no government tax incentives supporting the birth of the market, as happened for the wind and solar energy markets. Furthermore, technical norms must be consistent and non-impeditive for the hydrogen industry development. e. There are technological and cost challenges in hydrogen infrastructure, which require special metallurgy solutions for pipelines and tanks that are more expensive than conventional infrastructures. f. Non-existent technical professional training (currently limited to R&D). Lack of qualified human resources, both at the operational level and at the engineering and technology level, which means that the country will depend, at least for a long time, on international suppliers. The uncertainty and technological backwardness of the Brazilian industry in this sector make the scenario worse by making it difficult for new capital to enter, which usually enters where there is better added value. g. Realizing the energy use of hydrogen still presents significant technological and market challenges throughout its entire supply chain (production, transport, storage and consumption). h. The gas market in Brazil is still very recent when compared to other countries, having a reduced extent of the gas pipeline network, mostly concentrated in the coastal region. i. Need to build new infrastructure for hydrogen (storage and distribution) and limited infrastructure related to natural gas. j. No refuelling stations for use in vehicles with fuel cells. k. There is still no specific regulation for hydrogen use, transport and storage. l. There is a need to identify taxation and financing constraints, as well as the need to improve conditions for attracting investments in low-carbon hydrogen. m. In Brazil, the pre-salt geological formations have favourable characteristics for H2 storage, but the great distance from the pre-salt fields to the land should be considered. Great distances for hydrogen transport are costly. Absence of hydrogen in the energy matrix. n. A few commercial demo projects are in progress. o. Lack of production scale of national equipment (electrolysers, among others). p. PNH2 was published with excess routes and options at the strategic level. However, there is still no clear vision of the value potential of the demanding market, nor the definition of priorities, necessary to create a national strategy.

Table 3 - SWOT Matrix, Opportunities and Threats

Opportunities	Threats
a. Momentum in the international scenario of green hydrogen as a viable technology for the decarbonization of economies. b. World market demand for the acquisition of green hydrogen. c. Petrobras plans until 2026 to produce 100% of the diesel oil in its refineries with very low sulphur content (10 p.m.), indicating an increase in its consumption of hydrogen in the coming years (Petrobras, 2021). In 2031, consumption of around 375 thousand tons is projected. d. 95% of the hydrogen used in Brazil is produced from fossil sources, representing a great opportunity for the Brazilian industry to decarbonize. e. The PDE 2031 points out that the estimate of the total technical potential of hydrogen production in Brazil until 2050 should total 1.8 Gt/year, representing more than 14 times the world demand for hydrogen in 2018. f. Three possible hydrogen hubs lead the race in Brazil: Porto do Pecém and Porto do Açu, followed by the Porto do Suape initiative. These locations are industrial hubs with plans to produce green ammonia and other green commodities for domestic and international markets, creating an important synergy and developing new competitive advantages for the country. g. Hydrogen mixing in natural gas networks can contribute to expanding demand and increase the efficiency of the use of natural gas pipelines. h. Bill 725/2022 provides for the addition of hydrogen at the point of delivery or exit point in transport gas pipelines in mandatory minimum percentages in volume in the following progression: I – 5%, as of January 1, 2032; II – 10%, as of January 1, 2050. This regulation would minimize the need for infrastructure construction and associated costs. i. Research indicates that Brazil may have relevant natural or geological hydrogen potential in the São Franciso Basin and in at least four states (project by the companies GEO4U and Engie Brasil): Ceará, Roraima, Tocantins and Minas Gerais. j. Natural gas resources available in the country, which are associated with the technology for capturing and storing CO2, allow the production of blue hydrogen. k. Issues associated with the geological storage of hydrogen can be resolved within the scope of defining the regulatory framework for the storage of natural gas. l. An alternative to reduce costs is the production of electrolysers in Brazil, as the country has the necessary raw material (nickel reserves). m. Despite being very dependent on imports to meet its demand for fertilizers, Brazil has a strong agribusiness industry. Therefore, it is a great opportunity to produce hydrogen for fertilizers in Brazil, which could benefit from the National Fertilizer Plan. The same goes for ore, steel and other metals. Brazil produces and exports ore, steel and other metals, and these materials, with green certifications, could be premium products in the global commodities market in the coming decades. n. Use of turbinable run-off energy from hydroelectric plants for hydrogen production. o. Even with modest volumes, R&DI projects in the field of energy storage can have a very significant long-term impact on the greater insertion of variable renewables in the Brazilian electricity matrix. In particular, mention should be made of the projects for the production of hydrogen for energy storage at the Itaipu Technological Park, of Hytron for the companies BAESA and ENERCAN and, more recently, the project by Furnas at the Itumbiara Hydroelectric Power Plant (hydroelectric-solar	a. The lack of effective actions to attract investments to generate an additional market that demands H2. b. In most sectors, decarbonization via the adoption of green and blue H2 competes with other decarbonization solutions, such as biofuels and the use of fossil sources with carbon capture and storage (CCS). c. The green hydrogen market tends to be very competitive and the main consumers tend to be, at first, the European countries. The distance between Brazil and Europe may be a challenge. d. Strong competitors are taking place as other countries in Latin America and countries of the south of the European Union, Turkey and the countries of North Africa, which can export H2 to European countries through adapted gas pipelines. As for exports to Korea and Japan, competitors will be Australia and Vietnam. e. Agility of other governments, such as Chile and Australia, in planning and implementing structuring actions throughout the value chain to produce green H2 for export and local consumption. f. Hydrogen storage is a challenge. As the lightest chemical substance available, increasing energy density by volume requires high pressures for gaseous storage or cryogenics for liquid storage. g. Hydrogen is an explosive gas which affects social risk perception. h. The decision between centralized or distributed production of hydrogen can circumvent the inexistence of a transport and distribution network. Electrolysers or reformers can be installed close to the place of consumption. Therefore, the business model must be decided by the market. i. There is a lack of definition and understanding of the hydrogen diffusion model in the energy matrix to reveal the market sequence development that will catalyse its industry and avoid technological lock-in of segments that can be served by hydrogen in the future as its competitiveness increases. j. Mixing hydrogen into natural gas networks can bring about some changes to the end-use infrastructure, such as natural gas burners and turbines or modifications to compression systems. However, some countries have already set safe limits for hydrogen mixing in the pipeline system. Brazil still does not have consistent studies of these limits. k. Adding hydrogen to natural gas can decrease the capacity net power transmission from the pipeline system. While this does not give rise to any significant problems for a low-pressure supply operation, partial improvement of the compression system may become necessary. l. Low growth of the Brazilian economy and high indebtedness of the public machine, possibly impacting the volume of public and private investments in H2, as well as reducing consumer demand for the product.

Table 3 - SWOT Matrix, Opportunities and Threats (cont.)

Opportunities	Threats
photovoltaic – hydrogen). p. Hydrogen from ethanol, for example, may play a key role in the Brazilian automotive market and in other sugar and ethanol producing countries in the future (such as India, for example). Some automakers present developments, testing prototypes of fuel cell electric vehicles based on the reform of ethanol inside the vehicle or at the gas station. This means that most of the infrastructure is already available in Brazil, with little need for investments to overhaul the infrastructure. Still, synthetic fuels from other hydrogen routes will also play an important role. q. Potential for the use of hydrogen in heavy vehicles, such as trucks, locomotives, ships and aircraft. r. Hydrogen penetration in the production process of renewable hydrocarbons. s. Promotion of inclusive development of Brazilian society in the development process of this market, under the socioeconomic and educational aspects, also considering those related to the fiscal aspect. t. BNDES tends to assume a decisive role, as it did for the birth of the automobile industry, either by customizing its traditional lines of financing, or by raising financing in foreign currency, without exchange risk, as the greatest demand for hydrogen will be for export. u. The establishment of partnerships between the European Union and Brazil shows up as a very promising potential, given the concrete possibilities of exporting Brazilian green hydrogen to the European market, due to the high degree of energy insecurity and the commitments to reduce greenhouse gases of these countries. v. Green hydrogen can become an essential vector for the storage of the surplus of variable energy generation, in order to balance the grid, ensure system stability, assist in meeting demand peaks and, finally, maintain the energy system clean, efficient and sustainable. w. Decree No. 11,075, of May 19, 2022, established the procedures for the preparation of Sectoral Plans for Mitigating Climate Change and instituted the National System for Reducing Greenhouse Gas Emissions. Thus, creating a regulated carbon market, with a focus on exporting credits. x. Bill 1878/2022 suggests the Policy that regulates the production and uses of Green Hydrogen for energy purposes.	

3.2 Analysis of key points and recommended strategies

3.2.1 Strengths

Brazil has shown interest in developing its hydrogen strategy since 2002 with programs such as the Science, Technology and Innovation Program for the Hydrogen Economy (PROH2) (PEYERL, 2018). In the last two years, the country has taken important steps towards developing the hydrogen market, as the CNPE Resolution No. 2 of 2021, prioritizing the allocation of RD&I resources, among other topics related to the energy sector and the energy transition. The CNPE Resolution No. 6 of 2021 proposes guidelines for the National Hydrogen Program

(PNH2)(MACEDO; PEYERL, 2023). Then, launching the PNH2 in 2021 resulted in the elaboration of the Triennial Work Plan 2023-2025 in 2022, aiming to serve as a guide for the federal government's actions in developing the hydrogen sector in the coming years. Just as the country also has companies that operate in the hydrogen market and an association that brings together companies in the sector and other interested parties, the Brazilian Hydrogen Association (ABH2) (EPE, 2021a).

Brazil has the potential of diversified energy resources available from water, wind, solar, biofuels and biomass sources, including natural gas, the primary input in hydrogen production in the world (ELIZIÁRIO et al., 2020; EPE, 2021b). In addition, the great competitiveness of wind and solar sources has raised special interest in developing green hydrogen in the country by foreign and national partners (EPE, 2021a). The power sector has an energy policy with long-term planning and a consistent regulatory framework for the electrical system provided by ANEEL with an efficient contract compensation system provided by CCEE and a consolidated financing standard (BNDES) (CHAVES; DORES; DE CASTRO, 2021). This model can be replicated for hydrogen projects. CCEE is also coined for launching the first Hydrogen Certification in the Brazilian market; the initial version will certify the origin of green hydrogen production by water electrolysis (DE AZEVEDO, 2022). The certificate guarantees hydrogen sustainability attributes, ensures its environmental benefit, and increases investors' confidence in the Brazilian industry.

3.2.2 Weaknesses

The main barrier to green hydrogen is still the technology costs (MME/EPE, 2020), whether it's electrolysers for green hydrogen or CCUS technology for blue hydrogen. Additionally, institutional, legal and regulatory structures must be improved, adapting them to provide investors stability, predictability and confidence (MME; EPE, 2022b).

The gas market in Brazil is still very recent, having a reduced gas pipeline network, mostly concentrated in the coastal region (BRASIL-ALEMANHA, 2021; CHAVES; DORES; DE CASTRO, 2021), limiting its use for hydrogen transport. This issue implies the need for new infrastructure for hydrogen transport and storage (MME/EPE, 2020). The pre-salt geological formations have favourable characteristics for hydrogen storage, but the long distance from the pre-salt fields to land will require expensive transport (CNI, 2022).

The materialization of the use of hydrogen still presents significant technological and market barriers throughout its entire value chain (production, transport, storage and consumption) (MME, 2021b).

3.2.3 Opportunities

The PDE 2031 points out that the estimate of the total technical potential of hydrogen production in Brazil until 2050 should reach 1.8 Gt/year, representing more than 14 times the world demand for hydrogen in 2018 (MME; EPE, 2022b). Hydrogen is seen as a viable technology for the decarbonization of economies, busting a world market demand for the acquisition of green hydrogen and enabling domestic production for export and consumption (BRASIL-ALEMANHA, 2021).

Besides, green hydrogen can become an essential vector for storing the surplus of intermittent energy generation to balance the grid, ensure system stability, assist in meeting demand peaks and, finally, maintain the energy system clean, efficient and sustainable (GESEL - UFRJ, 2021).

Despite the competitiveness of renewables (wind and solar) for the production of green hydrogen, taking advantage of biofuels for producing hydrogen is another route to be explored, considering ethanol and biogas, once Brazil already has a well-established economy and infrastructure around this product (EPE, 2021b, 2021a; LAZARO; THOMAZ, 2021).

Issues associated with natural gas regulation can minimize the need for infrastructure construction, as geological storage of hydrogen can be solved within the scope of defining the regulatory framework for the storage of natural gas and the mixture of hydrogen in the natural gas grid. The possibility of mixing hydrogen with natural gas would allow free competition for the 9,409 km of transport gas pipelines, leveraging the New Gas Market (ELIZIÁRIO et al., 2020). In this direction, Senate's Draft Bill 725/2021 calls for hydrogen mixing obligation transport gas pipelines from 2032 (SENADO FEDERAL, 2022).

In Brazil, 95% of the hydrogen used is produced from fossil sources, representing a great opportunity for the Brazilian industry to decarbonize (CNI, 2022). The use of hydrogen in the Brazilian industry can be absorbed in sectors such as steel and metallurgical, petrochemical, food, flat glass and energy generation (BRASIL-ALEMANHA, 2021; EPE, 2021b).

The transport sector also represents a great opportunity for hydrogen introduction. Trucks used in the mining sector currently have high diesel consumption. For example, replacing one transport truck in mines is equivalent to taking fifty gasoline passenger cars off the streets. In addition to using trucks powered by fuel cells, other heavy vehicles operating in mines can be changed to this technology (CAVALCANTE; OLIVEIRA, 2022).

Even in light transport, hydrogen can play an important role, bringing yet another technological alternative to the vehicle electrifica-

tion process, either through fuel cells or, indirectly, through synthetic fuels (MME, 2021b).

Brazil has a strong agribusiness industry, becoming a great opportunity to produce hydrogen for fertilizers, which could benefit from the National Fertilizer Plan (MME; EPE, 2022b). After refineries, fertilizers represent Brazil's second greatest demand for hydrogen, with around 1,200 thousand Nm^3 or 87 thousand tonnes per year (CNI, 2022).

Green hydrogen projects in Brazil must be built in ports with industrial districts, which have the means to produce green ammonia and other green commodities for the domestic and international markets, creating important synergy and developing new competitive advantages for the country (MME; EPE, 2022b). Thus, hubs are being prospected in port regions, like Pecém Port, Açu Port, and Suape Port (CNI, 2022).

Expanding the hydrogen market will be very important to promote Brazilian society's technological and inclusive development under the socioeconomic and educational aspects.

3.2.4 Threats

Some threats are surrounding the hydrogen market, such as whether it will really be possible for this source to be competitive with other sources in the future (EPE, 2021a).

One of the worries that is raised in literature is about storage; as hydrogen is the lightest chemical substance available, increasing energy density by volume requires high pressures for gaseous storage or cryogenics for liquid storage, making this process expensive (EPE, 2021a, 2021b; GESEL - UFRJ, 2021). Avoiding technology lock-in is another challenge, as the market sometimes takes unexpected directions, and the market sequence catalyses the industry (EPE, 2021a).

It is necessary to consider possible competitive races in the supply of green hydrogen with Latin American countries such as Chile (BRASIL-ALEMANHA, 2021). As stated by (CNI, 2022), the great distance between Brazil and potential customers, as for the supply of the European Union (EU), strong competitors will be the countries of the South EU, Turkey and countries of North Africa, which will be able to export hydrogen to EU through adapted gas pipelines. As for exports to Korea and Japan, competitors will be Australia and Vietnam (CNI, 2022).

Brazil lacks effective actions to attract investments to generate an additional market for hydrogen demand (CNI, 2022). As the PNE 2050 points out, the Brazilian perception of hydrogen is like a disruptive future technology, while the global scenario envisions a market growth

with large-scale hydrogen technologies as early as 2040.

3.3 Performing GUT analysis

The GUT matrix will be used to rank the aspects evaluated in the SWOT analysis. The first step is to identify the relevance of each aspect of the analysed reports. To define the size of the relevance, the number of reports that defended each of the points in the four divisions of the SWOT analysis was identified. After that, the top points were selected so that the data to implement a GUT matrix was generated. Crossing Strengths and Weaknesses with Opportunities and Threats, the result is an index called relevance. Figure 1 brings these results, where through a heatmap, it is possible to see that the greenest stands for the highest relevance, yellow for the intermediate and red for the smallest relevance.

			Oportunities				Threats			
			World market demand	Hydrogen from ethanol	Hydrogen hubs	Hydrogen blend in natural gas network	Competitiveness of other countries	Chalanges and risk of hydrogen storage and transport	Lack of studies of mixing natural gas into natural gas network	Competitiveness with other decarbonization solutions
		Relevance	5	5	6	9	5	4	4	3
Strengths	International partnerships	6	30	30	36	54	30	24	24	18
	PNH pillars to develop a hydrogen Economy	6	30	30	36	54	30	24	24	18
	CNPE Resolutions for hydrogen development	7	35	35	42	63	35	28	28	21
	Competitiveness of variable renewables	9	45	45	54	81	45	36	36	27
Weaknesses	Technological and cost challanges	5	25	25	30	45	25	20	20	15
	Incipient natural gas market	4	20	20	24	36	20	16	16	12
	Institutional, legal and regulatory structures must be improved	3	15	15	18	27	15	12	12	9
	No specific regulation	2	10	10	12	18	10	8	8	6

Figure 1 - GTU Matrix for Hydrogen Development in Brazil

Based on this criterion, it is possible to see that:

I. Items presenting high punctuation (greener) are concentrated on the border Strengths and Opportunities, mostly in “competitiveness of variable renewables” on the side of Strengths and “hydrogen blend in natural gas network” on the side of Opportunities.

II. Items presenting lower punctuation (redder) are located along the side of Threats and Weakness, with the items between “no specific regulation” and “institutional, legal and regulatory structure must be improved” from the side of Weakness, and the item “competitiveness with other decarbonization solutions” on the side of Threats.

III. The GUT analysis shows that Brazil presents strong opportunities for hydrogen development than the other aspects of the SWOT analysis.

4. CONCLUSION

Hydrogen has been identified as an important component of global decarbonization. In this way, Brazil has a huge and diversified energy potential that can be driven by hydrogen production. This potential is attracting interest from investors to develop a hydrogen market both domestically and for export.

The SWOT and GUT analysis were used to analyse Brazil's hydrogen economy's status and provide strategies for promoting its development. About the strengths and opportunities found in the analysis, some can be highlighted:

I. The strong potential of renewables and their competitiveness in the Brazilian matrix, mainly wind and solar PV, which can be used to produce green hydrogen with competitive energy prices;

II. The regulation of the New Gas Market can be improved to minimize additional costs with hydrogen infrastructure, as the geological storage of hydrogen can be resolved within the scope of defining the regulatory framework for natural gas storage. Also, the mixture of hydrogen in the natural gas grid. The possibility of mixing hydrogen with natural gas would allow free competition for the 9,409 km of transport gas pipelines.

In the next years, Brazil is expected to experience an energy surplus due to the electricity market deregulation. Consumers will be able to purchase electricity directly from generators and traders (nowadays, only large high-voltage consumers have this option), leaving distribution utilities an energy surplus based on long-term PPAs (Power Purchase Agreements). In this context, energy prices tend to be low, which may represent an opportunity for using electricity, mainly from hydropower, to produce green hydrogen.

About the weaknesses and threats found in the analysis, here are some highlights:

I. The main weakness found in the literature is the cost of the entire green hydrogen production chain. So, this technology needs to be developed and scaled to become more competitive. But this will require efforts not only from Brazil, but from the world.

II. Competitiveness with other countries, even in Latin America, threatens Brazil. The country is struggling to launch its hydrogen strategy. The country has shown signs of delay in its planning, mainly by launching a Triennial Plan, focusing only on studies during a period

that seems too long. The country is not focused on putting together its strategy, setting goals and showing investors that it is interested in developing a hydrogen economy.

The technical, political and economic difficulties in deploying a hydrogen economy in Brazil highlight the need for a different energy policy, including:

I. PNH does not focus on a specific technology. It opens a range of different types of hydrogen, does not address the main types of hydrogen potential, and does not focus on what the global market has invested.

II. Some initiatives have been taken to develop a hydrogen market. Still, they are not enough, both from the point of view of technological development, legal and regulatory frameworks.

III. Brazil is not showing clear signs of providing a security policy for investors who are prospecting the country for the development of hydrogen projects.

IV. The northeast region has taken some steps, but a state movement is insufficient. The country as a whole must be aligned with this new market's development possibilities, providing investors with legal and regulatory stability.

V. Several public policies used in the development of renewables, such as wind and solar sources, can be used to expand the hydrogen market, for example, the Reidi (Special Regime of Incentives for the Development of Infrastructure), green hydrogen projects could be included in the program.

VI. Grid availability may be a concern for developing hydrogen projects, since most renewable plants are not allowed to connect to the grid due to the lack of infrastructure (transmission lines and substations).

Brazil has not shown signs of implementing a clear hydrogen strategy, with goals to be achieved. The Triennial Plan presents necessary actions to be developed but over a very long period. If Brazil creates its strategy based on studies from the three-year plan, it will only be launched after 2025. The country is losing the world investment time within Latin America itself. Countries like Chile and Colombia already have their strategies ready, giving positive signals to investors.

Brazil needs to accelerate its strategy, as developing a hydrogen economy can bring numerous benefits beyond environmental improvement. Establishing this new technology will require human resources, which means that the qualification of professionals will be key to keeping and developing this economy. Meaning that this whole process

can contribute significantly to people´s prosperity and, at the same time to the country´s growth.

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