A Systematic Review of the Regulation of Green Hydrogen-Based Electricity Generation in Brazil

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This article presents a systematic review of the current state of the art regulating electricity generation from green hydrogen in Brazil. The study was conducted through searches using selected descriptors in the SciELO and Google Scholar databases, supplemented by consultations in the ANEEL Virtual Library, Google, and ChatGPT. The goal was to identify documents related to laws, norms, and regulations addressing the use of green hydrogen for electricity generation in Brazil without any temporal restriction. The analysis of multiple documents revealed that, to date, no regulatory framework has been officially approved for green hydrogen in Brazil. This regulatory gap highlights the need for comparative studies with legislation from other countries to inform the development of an appropriate framework for the Brazilian context.
Keywords: Green Hydrogen; H2V; Brazil Legal Regulation; Brazilian Legislative Framework; Energy Legislation in Brazil.

The global discourse on sustainable development gained momentum at the World Summit on Sustainable Development (Rio 92) [1], a United Nations (UN) forum that deliberated on strategies to mitigate greenhouse gas emissions and decarbonize the global energy matrix. Out of these discussions emerged the Sustainable Development Goals (SDGs) [2], a universal call to action aimed at ending poverty, protecting the environment, combating climate change, and fostering peace and prosperity for all.

In pursuit of these objectives, numerous technological advancements have been made globally to maintain international competitiveness while progressing toward energy transition goals. One such innovation is green hydrogen, which major global players have heralded as a critical tool for achieving planetary decarbonization.

While the concept of a "Hydrogen Economy" was first coined in the 1970s as a response to oil crises and embargoes, the vision for hydrogen as a renewable energy carrier dates back to the late 19th and early 20th centuries. For instance, Poul la Cour utilized wind energy and electrolysis to produce hydrogen and oxygen between 1891 and 1908. Similarly, in 1923, J.B.S. Haldane hypothesized a future where wind-powered electrolysis could supply high-voltage electricity grids, with surplus energy used to decompose water into hydrogen and oxygen [3]. These early examples underscore the long-standing recognition of hydrogen's potential, although technical and economic challenges historically limited its application to niche markets.

Today, classifying hydrogen based on the carbon intensity of its production process is a critical step in understanding its role in decarbonization. According to the Energy Research Agency [4], hydrogen is categorized into different "colors" depending on the production pathway, associated costs, and the extent of carbon dioxide management through Carbon Capture, Utilization, and Storage (CCUS). Figure 1 illustrates this classification system, reflecting the diverse routes available for hydrogen production. This evolving understanding of hydrogen's potential and production routes underscores its significance as a cornerstone of the global energy transition.

Brazil is uniquely positioned to leverage green hydrogen for its energy transition. Eighty-five percent of its energy matrix is derived from clean sources of electricity generation free from carbon dioxide emissions. The remaining 15 percent

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Figure 1. Summary of the hydrogen production process.

Color	Summary of the hydrogen production process
Black	Coal gasification (anthracite[1]) without CCUS[2]
Brown	Coal gasification (hulha[3]) without CCUS
Gray	Steam reforming of natural gas without CCUS
Blue	Steam reforming of natural gas with CCUS
Turquoise	Pyrolysis of methane[4] whithout generating CO_2
Green	Water electrolysis with energy from renewable sources (wind/solar)
Moss	Catalytic reforming, gasification of waste plastics or anaerobic biodigestion of biomass or biofuels with or without com energia de fontes renováveis (eólica/solar)
Pink	Nuclear power source
Yellow	Power from the electrical grid, composed of several sources
White	Extraction of natural or geological hydrogen

Notes: 1 - From the least to the rechest types in carbon: carbon, peat, lignite, hard coal and anthracite, the latter having more than 86% carbon. 2 - CCUS - *Carbon Capture, Utilization and Storage*. 3 - Hard coal has between 69% and 86% carbon. 4 - Pyrolysis of methane is understood as pyrolysis of natural gas, cince it is the main component of natural gas.

Source: EPE, Technical Note: May 2021 p. 4 [4].

comes from thermal power plants powered by diesel or biodiesel, as reported in the ANEEL Retrospective 2022.

This remarkable distribution reflects Brazil's reliance on renewable resources such as hydroelectric, wind, solar, and biomass energy. Figures 2 and 3 illustrate the breakdown of energy production sources, providing insights into the diversity of production methods and the origin of the fuels used.

Such a predominantly renewable energy matrix positions Brazil as a global leader in clean energy, making it an ideal candidate for large-scale green hydrogen production. By harnessing its abundant renewable resources, Brazil has the potential to produce green hydrogen sustainably and cost-effectively, supporting both domestic energy needs and international markets aiming to decarbonize their energy systems.

This context underscores the strategic importance of developing a robust regulatory framework for green hydrogen that aligns with Brazil's energy strengths while addressing the gaps identified in comparative global studies.

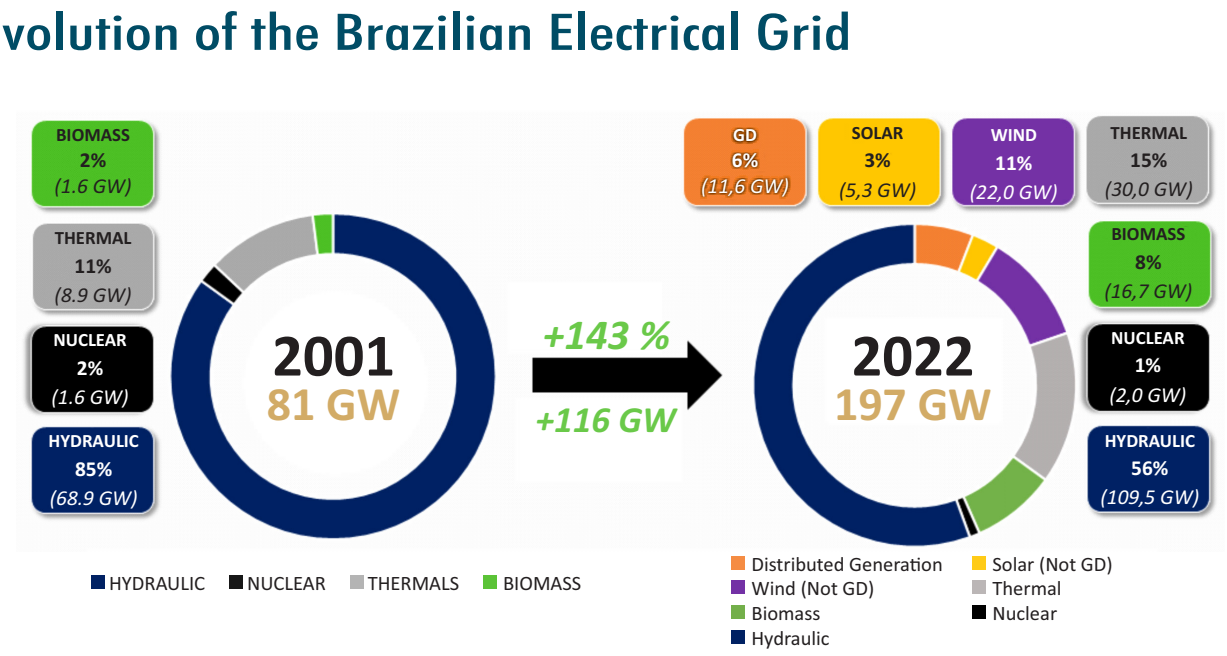
There is strong evidence of Brazil's commitment to prioritizing electricity generation from clean and decarbonized sources and significant growth in wind and solar power generation. These renewable sources are increasingly leveraged for green hydrogen production due to their declining costs, which have dropped consistently year after year. This unique combination of factors positions Brazil as one of the top global contenders for developing a robust Green Hydrogen Industry, as recognized by multiple energy agencies and working groups focused on green hydrogen.

However, establishing a green hydrogen supply chain requires more than abundant renewable resources. It necessitates creating a comprehensive regulatory framework encompassing legislation, regulations, and standards to provide the legal certainty needed to attract the investments essential for this industry's emergence and growth.

Goals

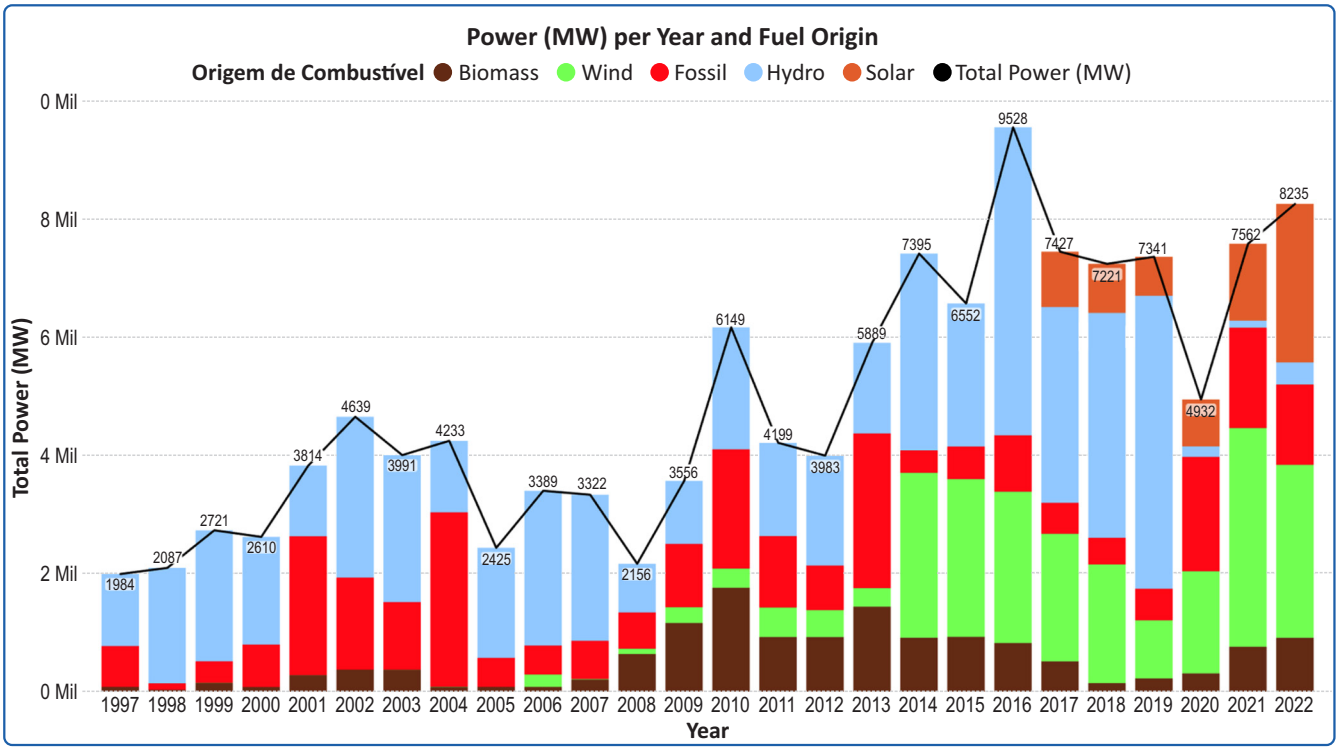
The primary objective of this study is to examine the state of the art in regulating the

Figure 2. Evolution of the electrical matrix in Brazil.



Source: ANEEL 2022 Retrospective, p. 26.

Figure 3. Power per year and fuel origin.



Source: ANEEL 2022 Retrospective, p. 27.

production of electricity from green hydrogen in Brazil. While most published works in Brazil focus on methods for producing green hydrogen (H2V) or highlight case studies of Research and Development (R&D) projects, they rarely address the existing legislation necessary to regulate this nascent and promising industry.

Insights from studies by Polish and German researchers emphasize the global regulatory gap in this emerging sector, sparking interest in exploring Brazil's regulatory landscape for electricity production from green hydrogen. This investigation holds particular relevance given the potential of green hydrogen to replace or eliminate the 15% of fossil fuels still present in Brazil's energy matrix.

Moreover, Brazil's strong and judicious regulatory framework for electricity production heightened the importance of this subject. Understanding how this framework might accommodate or adapt to the development of a green hydrogen industry is critical to shaping its future role in Brazil's clean energy transition.

Materials and Methods

Using the following descriptors: ("Green Hydrogen " OR H2V) AND ("Legal Regulation" OR " Current Legislative Framework" OR " energy legislative ") papers were searched in the Scielo and Google Scholar databases, with 122 and 39 papers identified, respectively. To search for papers more focused on the theme, only those in which the descriptors appear in the title were considered. a search in the Legislation issued by the National Electric Energy Agency of Brazil – ANEEL, using the ANEEL Virtual Library, which is a research tool available on the internet, on the ANEEL website, whose address will be part of the references of this work [5]. A search for this topic was also carried out, using Google and ChatGPT to identify documents dealing with Laws, Rules and Regulations on the use of Green Hydrogen in Brazil for the generation of Electric Energy that had been issued by other authorities. different from the National Electric Energy Agency.

Results and Discussion

Findings from the ANEEL Virtual Library

When the term green hydrogen was searched in ANEEL's Virtual Library, only four documents were identified:

Two Ordinances (PRTs) [6]: These addressed administrative matters related to ANEEL staff participation in international events (e.g., seminars and workshops) focused on energy transition, market regulation, and green hydrogen. While these documents did not contribute directly to the study's objectives, they indicated ANEEL's interest in the topic.

Two Regulatory Impact Analyses (AIRs):

- Five-Year Strategic Innovation Plan (PEQuI 2023–2028) ((Report on Regulatory Impact Analysis No. 0001/2023-SPE/ANEEL) [7]): Addressed general innovation and strategic goals for the energy sector but did not include specific green hydrogen regulations.
- Locational Signal for TUST/TUSDg ((Report on Regulatory Impact Analysis No. 03/2022-SGT/ANEEL) [8]): Examined regulatory impact analysis related to tariff methodologies but did not mention green hydrogen.

When analyzing the 04 documents located, it is identified that the ordinances deal with administrative matters of ANEEL and served to release the removal of the agency's employees from the country to participate in Seminars, Workshops, and technical visits on energy transition, market regulation, green hydrogen, and decarbonization, in an event held in Portugal. Despite not adding content to develop the results intended by the work in question, they demonstrated the topicality of the topic discussed and the interest of the National Electric Energy Agency.

Analysis of Relevant Normative Resolutions

ANEEL Normative Resolution No. 1,029 (07/25/2022) [9]: Consolidates norms related to the production and commercialization of electricity. While it defines procedures for maintaining operational conditions and power specifications for electricity generation enterprises, it does not explicitly address green hydrogen.

ANEEL Normative Resolution No. 1,033 (07/26/2022) [10]: Consolidates regulations under the Alternative Sources Incentive Program (PROINFA), including criteria for quality and reliability of electricity generation services. However, it does not mention green hydrogen.

The results demonstrate a notable lack of specific regulations or guidelines for producing electricity from green hydrogen within ANEEL's framework. While the identified documents suggest a growing interest in the topic, particularly through international engagement and strategic planning, no concrete regulatory framework is currently in place.

This gap aligns with global observations about the nascent state of regulatory frameworks for green hydrogen, as noted in comparative studies from countries such as Poland and Germany.

The absence of clear legislation in Brazil highlights the urgency of establishing policies to foster the development of this promising industry, especially given Brazil's renewable energy potential and the opportunity to eliminate the remaining 15% reliance on fossil fuels in its energy matrix.

Future research should explore comparative international legislation and propose actionable recommendations for Brazil's regulatory framework to accelerate the development of a green hydrogen-based energy system.

The findings underscore the evident lack of regulation by the National Electric Energy Agency (ANEEL) concerning the production and use of green hydrogen for electricity generation. To address this gap, the search was expanded using Google and ChatGPT, which led to identifying key legislative and policy documents related to green hydrogen in Brazil.

Key Documents Identified

Draft Bill No. 1878/2022 [11]: This bill, proposed by the Environment Commission of the Federal Senate of Brazil [8], aims to establish a policy framework to regulate the production and use of green hydrogen for energy purposes. The draft was forwarded to the Special Commission for the Debate of Public Policies on Green Hydrogen for further analysis on April 20, 2023.

Roadmap for Structuring the Hydrogen Economy in Brazil (2005) [12]: Published by the Ministry of Mines and Energy (MME), this document outlines strategic directions for integrating hydrogen into Brazil's energy sector. It includes recommendations to promote norms and standards for certification of products, processes, and services related to hydrogen and fuel cell technologies.

Science, Technology, and Innovation Program for the Hydrogen Economy (ProH2, 2002): Developed by the Ministry of Science and Technology (MCTI), this program emphasizes fostering innovation in hydrogen technologies and calls for establishing technical standards and regulatory frameworks [13].

Current Status and Observations

Despite the presence of these initiatives, Brazil does not have an approved regulatory framework specifically addressing green hydrogen as of 2023. While the identified documents demonstrate intent and preliminary planning, the lack of concrete regulations hinders establishing a structured green hydrogen industry. This regulatory vacuum presents a significant

barrier to attracting investments and enabling the large-scale deployment of green hydrogen technologies. The absence of clear guidelines also delays Brazil's ability to capitalize on its abundant renewable resources and strategic position as a potential leader in the global green hydrogen market.

Next Steps

The draft of Bill No. 1878/2022 represents a critical opportunity to establish foundational regulations for green hydrogen. Advocating for its swift approval and implementation should be a priority.

Efforts to update and operationalize the Roadmap and ProH2 [14] program recommendations are necessary to translate policy objectives into actionable outcomes.

Comparative analysis with regulatory frameworks from other countries could provide valuable insights to accelerate Brazil's progress in this emerging sector.

Conclusion

The systematic review of the existing regulatory framework for using green hydrogen in electricity production in Brazil highlights a critical gap: the lack of norms and regulations issued by the Brazilian Legislature (Federal Chamber of Deputies and Federal Senate) and the National Electric Energy Agency (ANEEL). This absence signifies a complete lack of legal protections for the commercial-scale use of green hydrogen, whether for domestic consumption or export.

This regulatory void not only underscores the absence of a structured framework but also highlights the challenges of accessing consolidated and comprehensive information on existing and proposed regulations related to green hydrogen in Brazil.

Furthermore, the lack of clear rules and legal certainty appears to deter investment in this promising industry, potentially limiting Brazil's ability to develop and capitalize on its immense potential as a global leader in green hydrogen production.

Recommendations

The study identifies a significant gap that suggests the necessity of conducting a comparative analysis of existing regulations and standards in the world's five largest hydrogen-producing countries—namely, the United States, the United Kingdom, Germany, Ukraine, and Russia. This analysis should also include Chile and Argentina, given their geographical proximity to Brazil and their potential role as competitors in exporting green hydrogen to Europe. Such a study could provide insights and best practices to guide the development of Brazil's regulatory framework and enhance its competitive positioning in the global market.

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References

1. 30 years of Rio-92: the legacy of the 'greatest ecological conference of all time' - BBC News Brasil, on 07/30/2023.
2. UN. Sustainable Development Goals – SDGs. Available at: https://brasil.un.org/pt-br/sdgs accessed on 07/17/2022.
3. Pivovar BR, Satyaple S. Hydrogen at Scale (H2@ Scale): Key to a Clean, Economic, and Sustainable Energy System. Electrochem. Soc Interface 2018;47-52. Accessed on 07/17/2022.
4. EPE. Technical Note. Production and Consumption of Hydrogen in Refineries in Brazil, 2022. p. 4. Accessed on 07/15/2022. https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-667/NT-EPE-DPG-SDB-2022-01%20-%20Hidrog%C3%AAnio %20

in%20Refineries.pdf .
5. https://biblioteca.aneel.gov.br/. ANEEL Virtual Library.
6. ANEEL. PRT - Ordinance 134/2022 and PRT - Ordinance 155/2022. Accessed on 7/3/2024.
7. ANEEL. Five-Year Strategic Innovation Plan – PEQuI 2023-2028 of the ANEEL PDI Program (Regulatory Impact Analysis Report No. 0001/2023-SPE/ANEEL).
8. ANEEL. Location Sign Result – TUST/ TUSDg (Regulatory Impact Analysis Report No. 03/2022-SGT/ANEEL).
9. ANEEL. ANEEL Normative Resolution No. 1.029, of July 25, 2022. https://www2.aneel.gov.br/cedoc/ren20221029.pdf.
10. ANEEL. ANEEL Normative Resolution No. 1.033, of July 26, 2022. https://www2.aneel.gov.br/cedoc/ren20221033.pdf
11. Federal Senate Bill No. 1878, 2022. https://www25.senado.leg.br/web/atividade/materias/-/materia/153923.
12. MME. Roadmap for Structuring the Hydrogen Economy in Brazil (2005), available at: MME – Ministry of Mines and Energy (2005). Roadmap for Structuring the Hydrogen Economy in Brazil. (General coordination: MME – Ministry of Mines and Energy; Technical Integration: MCT – Ministry of Science and Technology; Operation: LACTEC/UFPR).
13. Science, Technology and Innovation Program for the Hydrogen Economy (ProH2, 2002) of the Ministry of Science and Technology (MCTI). https://www.h2verdebrasil.com.br/no-brasil/#:~:text=O%20roteiro%20emfatizava%20o%20uso,energia%20solar%2C%20e%C3%B3lica%20e%20hidrel%C3% A9trica.
14. MME. Proposed guidelines for the National Hydrogen Program PNH2. Available at: https://www.epe.gov.br/sites-pt/sala-de-imprensa/noticias/PublishingImages/Paginas/MME-apresenta-ao-CNPE-proposta-de-diretrizes-para-o-Programa -Nacional-do-Hydrogen-PNH2/HydrognioRelatriodiretrizes.pdf.