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Between Opportunity and Regulatory Alignment: Challenges for Brazilian Green Hydrogen in Meeting European Union Standards

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Oportunidade e Adequação Regulatória: Desafios do Hidrogênio Verde Brasileiro frente às Exigências da União Europeia

RESUMO

Objetivo - Analisar os desafios regulatórios do Brasil para adequar sua produção de hidrogênio verde (H_2V) e derivados, como o aço verde, às exigências da União Europeia.

Metodologia - Análise documental de marcos regulatórios do Brasil e da União Europeia e estudo de caso comparativo sobre o modelo alemão de regulação do hidrogênio.

Originalidade/relevância - Análise do descompasso entre o potencial exportador de H_2V do Brasil e a inadequação de seu arcabouço regulatório frente às normas da UE. A relevância está em discutir a convergência regulatória como fator crítico para a competitividade brasileira na economia de baixo carbono.

Resultados - Os resultados apontam que o marco regulatório nacional é insuficiente e desalinhado dos critérios europeus de adicionalidade, temporalidade e rastreabilidade. A ausência de um sistema de certificação emerge como o principal entrave à exportação do H_2V e do aço verde, comprometendo a competitividade do país.

Contribuições teóricas/metodológicas - O trabalho articula os campos da regulação energética, política industrial e comércio internacional no contexto da transição energética.

Contribuições sociais e ambientais - No âmbito social, o estudo subsidia políticas para a reindustrialização verde. Ambientalmente, indica como o Brasil pode materializar seu potencial para acelerar a descarbonização global, viabilizando a exportação de hidrogênio de baixa emissão de carbono e seus derivados.

PALAVRAS-CHAVE: Transição Energética. Hidrogênio Verde. Regulação.

Between Opportunity and Regulatory Alignment: Challenges for Brazilian Green Hydrogen in Meeting European Union Standards

ABSTRACT

Objective – This study aims to analyze the regulatory challenges faced by Brazil in aligning its green hydrogen (GH_2) and derivative production, such as green steel, with the requirements established by the European Union (EU).

Methodology – The research is based on a documentary analysis of regulatory frameworks in both Brazil and the EU, complemented by a comparative case study of the German hydrogen regulation model.

Originality/Relevance – The paper highlights the regulatory gap between Brazil's export potential for GH_2 and the misalignment of its domestic framework with EU standards. The relevance lies in discussing regulatory convergence as a critical factor for Brazil's competitiveness in a low-carbon global economy.

Findings – The results indicate that Brazil's current regulatory framework is insufficient and misaligned with key European criteria, particularly regarding additionality, temporal correlation, and traceability. The absence of a national certification system emerges as the main barrier to the export of GH_2 and green steel, undermining the country's global competitiveness.

Theoretical/Methodological Contributions – This study bridges the fields of energy regulation, industrial policy, and international trade within the context of the energy transition.

Social and Environmental Contributions – On the social front, the research informs policy design for green reindustrialization. From an environmental perspective, it outlines how Brazil can leverage its renewable potential to accelerate global decarbonization by enabling the export of low-carbon hydrogen and its derivatives.

KEYWORDS: Energy Transition. Green Hydrogen. Regulation.

Entre la Oportunidad y la Adecuación Regulatoria: Desafíos del Hidrógeno Verde Brasileño frente a las Exigencias de la Unión Europea

RESUMEN

Objetivo – Analizar los desafíos regulatorios que enfrenta Brasil para adecuar su producción de hidrógeno verde (H_2V) y sus derivados, como el acero verde, a las exigencias de la Unión Europea (UE).

Metodología – Análisis documental de los marcos normativos de Brasil y de la Unión Europea, complementado por un estudio de caso comparativo del modelo alemán de regulación del hidrógeno.

Originalidad/relevancia – El estudio examina la brecha entre el potencial exportador de H_2V de Brasil y la insuficiencia de su marco normativo frente a las normativas europeas. Su relevancia radica en discutir la convergencia regulatoria como un factor clave para la competitividad brasileña en la economía global baja en carbono.

Resultados – Los resultados indican que el marco regulatorio nacional es insuficiente y se encuentra desalineado con los criterios europeos de adicionalidad, correlación temporal y trazabilidad. La ausencia de un sistema nacional de certificación surge como el principal obstáculo para la exportación de H_2V y acero verde, comprometiendo la competitividad del país.

Contribuciones teóricas/metodológicas – El trabajo articula los campos de la regulación energética, la política industrial y el comercio internacional en el contexto de la transición energética.

Contribuciones sociales y ambientales – En el ámbito social, el estudio aporta insumos para la formulación de políticas de reindustrialización verde. En el plano ambiental, señala cómo Brasil puede materializar su potencial para acelerar la descarbonización global, posibilitando la exportación de hidrógeno de bajas emisiones de carbono y sus derivados.

PALABRAS CLAVE: Transición Energética. Hidrógeno Verde. Regulación.

1 INTRODUCTION

The transition to a low-carbon global economy poses complex challenges, particularly for the decarbonization of difficult-to-decarbonize industrial sectors (*hard-to-abate*)[1]. Between the seaters *hard-to-abate*, high-energy-intensity industrial segments stand out, such as the steel industry, in addition to maritime, air and road freight transport[2]. Together, these sectors account for about 50% of global CO_2 emissions, and if current trends continue, their emissions could increase significantly by 2050.[3]. Their transition is particularly challenging and slow, as many national climate plans devote little specific attention to these areas.[4], due to technical, economic and political obstacles, in addition to the immaturity of some low-carbon technologies[5]. Moreover, recent studies indicate that the reliability and efficiency of HVDC transmission systems are essential for integrating renewable sources at scale, contributing to the reduction of faults and energy losses.[6]

In this context, several technological solutions and energy vectors have been explored, including low-emission hydrogen, in particular, green hydrogen (H_2V)[7], emerges as a promising alternative. In the European Union, for example, H_2V has been integrated into energy security and industrial policy strategies.[8], reflecting an effort to reduce dependence on fossil fuels and foster new value chains. In contrast, nations with vast renewable resources, such as Brazil, see the opportunity to position themselves as strategic suppliers in this new market.

Realizing this opportunity, however, is not without its complexities. It depends on overcoming technical, economic, and, crucially, regulatory barriers. In particular, the European Union has developed a regulatory framework that serves as a standard for the global market, establishing

[1] OECD, 2025. Hydrogen in steel: addressing emissions and dealing with overcapacity. Paris: Organisation for Economic Co-operation and Development. Available at: https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/03/hydrogen-in-steel_f4d15f8d/7e2edc69-en.pdf (Accessed on: 04/20/2025)

[2] OECD, 2025. **Hydrogen in steel**: addressing emissions and dealing with overcapacity. Paris: Organisation for Economic Co-operation and Development. Disponível em: https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/03/hydrogen-in-steel_f4d15f8d/7e2edc69-en.pdAccessed on: July 12, 2025.

[3] GROPPI, D. *et al*. Energy modelling challenges for the full decarbonisation of hard-to-abate sectors. **Renewable and Sustainable Energy Reviews**, v. 209, p. 115103, 2025. ISSN 1364-0321. Available at: https://doi.org/10.1016/j.rser.2024.115103. Accessed on: August 12, 2025.

[4] ENERGY TRANSITIONS COMMISSION (ETC). **Mission Possible**: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century. London, nov. 2018. 172 p. Disponível em: https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC_MissionPossible_FullReport.pdf. Accessed on: August 12, 2025.

[5] GROPPI, D. *et al*. Energy modelling challenges for the full decarbonisation of hard-to-abate sectors. **Renewable and Sustainable Energy Reviews**, v. 209, p. 115103, 2025. ISSN 1364-0321. Available at: https://doi.org/10.1016/j.rser.2024.115103. Accessed on: August 12, 2025.

[6] MELO, Messias Silva de; LOPES NETO, Guilherme Alexandre; BERTHO JUNIOR, Rui; BRANCO, Hermes Manoel Galvão. Localização de faltas em sistemas HVDC utilizando Perceptron Multicamadas e Transformada Wavelet Packet: uma abordagem sustentável para a integração de energias renováveis. **Fórum Ambiental da Alta Paulista**, v. 21, n. 1, 2025. Disponível em: https://publicacoes.amigosdanatureza.org.br/index.php/forum_ambiental/article/view/5589. Acesso em: 24 set. 2025.

[7] Produced through the electrolysis of water using renewable energy, particularly solar and wind sources.

[8] EUROPEAN UNION. European Commission.**A hydrogen strategy for a climate-neutral Europe**[COM(2020) 301 final]. Brussels: European Commission, 2020. Available at: https://eur-lex.europa.eu/legal-content/PT/ALL/?uri=CELEX:52020DC0301. Accessed on: August 12, 2025.

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rigorous validation criteria for hydrogen, considered green, and its derivatives. Instruments such as the Taxonomy Regulation and the Renewable Energy Directive (RED II/III) define technical prerequisites—such as additionality, temporality, and traceability—that third-country production must meet to access the European market. This dynamic creates a scenario of mandatory regulatory convergence for nations that, like Brazil, aspire to export such commodities.

Against this backdrop of challenges and opportunities, this article aims to investigate a central issue: what are the main regulatory hurdles Brazil must overcome to ensure its production of green hydrogen and industrial derivatives meets the sustainability criteria defined by the European Union? Furthermore, it seeks to understand to what extent the German regulatory model can inform the design of Brazil's strategy. Thus, the objective of this paper is to analyze the challenges of regulatory convergence for Brazil in the field of green hydrogen, focusing on the alignment of its production and certification systems with European standards and the potential for developing a low-carbon steel industry.

The central thesis defended here is that Brazil's regulatory and institutional framework for hydrogen is currently incipient and insufficient to ensure automatic alignment with European requirements. It is argued that EU regulation acts as an exogenous driver, pushing for the modernization and sophistication of domestic policies, while also representing a window of opportunity for Brazil to add value to its energy resources. To develop this thesis, the article examines the European regulatory architecture, diagnoses the national regulatory framework, and uses the German case as a reference to, ultimately, outline the paths and conditions for Brazil's strategic insertion into the nascent global green hydrogen economy.

2 THE ROLE OF GREEN HYDROGEN IN EUROPEAN INDUSTRIAL DECARBONIZATION

2.1 EU climate targets and the role of H_2V

Over the past decade, the European Union (EU) has consolidated an ambitious path towards energy transition and decarbonization. Since 2014, it has aimed to reduce greenhouse gas emissions by 40% by 2030 (compared to 1990). This ambition was intensified with the European Green Deal

(*Green Deal*), which aims to achieve climate neutrality by 2050 and led to the increase of the reduction target to 55% by 2030, under the "*Fit for 55*"[9].

The energy crisis resulting from the 2022 invasion of Ukraine accelerated this transition, highlighting Europe's dependence on fossil fuels and the urgent need for energy security.ica[10]. In response, the EU expanded clean energy production, standing out on the global stage for its rapid adoption of sources such as solar and wind, which, in 2024, accounted for 29% of the region's electricity generation. Despite these advances,energy mixof the EU still contains a presencesignificant oil (32%) and natural gas (25%)[11], requiring additional efforts for complete decarbonization, especially in the transport and industrial sectors[12]. In thatcontext, green hydrogen[13]has been considered a key technology to decarbonize sectors that are difficult to electrify, such assectorsenergy-intensive industriesand long-distance transportation[14]. More specifically, since 2019, the EU has been actively promoting the development of a hydrogen economy, with the publication of the *European Hydrogen Energy Roadmap pelo Fuel Cells and Hydrogen Joint Undertaking* (FCH JU). This roadmap identified hydrogen, especially that produced from renewable sources, as a key driver for achieving the EU's climate goals. It proposed infrastructure development, technological implementation, and the training of a specialized workforce in this sector.[15].

The importance of green hydrogen was reinforced through the *European Green Deal,* launched in 2021, which mobilizes up to €1 trillion in investments and triggered a strong push in innovation and production of clean hydrogen[16]. A *Hydrogen Strategy for a Climate-Neutral Europe* predicts that, between 2025 and 2030, hydrogen will be integrated into the European energy system, reaching 40 GW of installed capacity and the production of 10 million tons, advancing towards large-scale implementation in sectors that are difficult to decarbonize from 2030 onwards[17]. In parallel,

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[9] EUROPEAN COMMISSION. **Going climate-neutral by 2050: a strategic long-term vision for a prosperous, modern, competitive and climate-neutral EU economy**.Luxembourg: Publications Office of the European Union, 2019. Available at:https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en . Accessed on: July 22, 2025.

[10] EUROPEAN UNION. European Commission.**EU action to tackle the energy crisis**. Brussels: European Commission, [n.d.]. Available at: https://commission.europa.eu/topics/energy/eu-action-address-energy-crisis_pt . Accessed on: August 12, 2025.

[11] INTERNATIONAL ENERGY AGENCY (IEA). **Energy mix**. *In*: INTERNATIONAL ENERGY AGENCY. Europe. Available at: https://www.iea.org/regions/europe/energy-mix. Accessed on: August 12, 2025.

[12] JENSEN, L. **EU climate target plan: raising the level of ambition for 2030**.Brussels: European Parliamentary Research Service, Dec. 2020. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659370/EPRS_BRI(2020)659370_EN.pdf . Accessed on: July 22, 2025.

[13] Produced through the electrolysis of water using renewable energy, particularly solar and wind sources.

[14] INTERNATIONAL ENERGY AGENCY (IEA). **Hydrogen**. Available at: https://www.iea.org/energy-system/low-emission-fuels/hydrogen . Accessed on: August 12, 2025.

[15] ISLAM, A. *et al*. Accelerating the green hydrogen revolution: a comprehensive analysis of technological advancements and policy interventions. **International Journal of Hydrogen Energy**, v. 67, p. 458–486, 2024. ISSN 0360-3199. Available at: https://doi.org/10.1016/j.ijhydene.2024.04.142 . Accessed on: July 21, 2025.

[16] LEGGERINI, C.; BANNÒ, M.; DAL MOLIN, M. Hydrogen innovation: An exploration of its determinants across Europe. **Energy Policy**, [S.l.], v. 204, p. 114675, 2025. ISSN 0301-4215. Available at :https://www.sciencedirect.com/science/article/pii/S030142152500182X . Accessed on: July 14, 2025.

[17] H2GreenTECH. **A Hydrogen Strategy for a Climate-Neutral Europe.**2020. Available at: https://www.h2greentech.eu/a-hydrogen-strategy-for-a-climate-neutral-europe/. Accessed on: August 12, 2025.

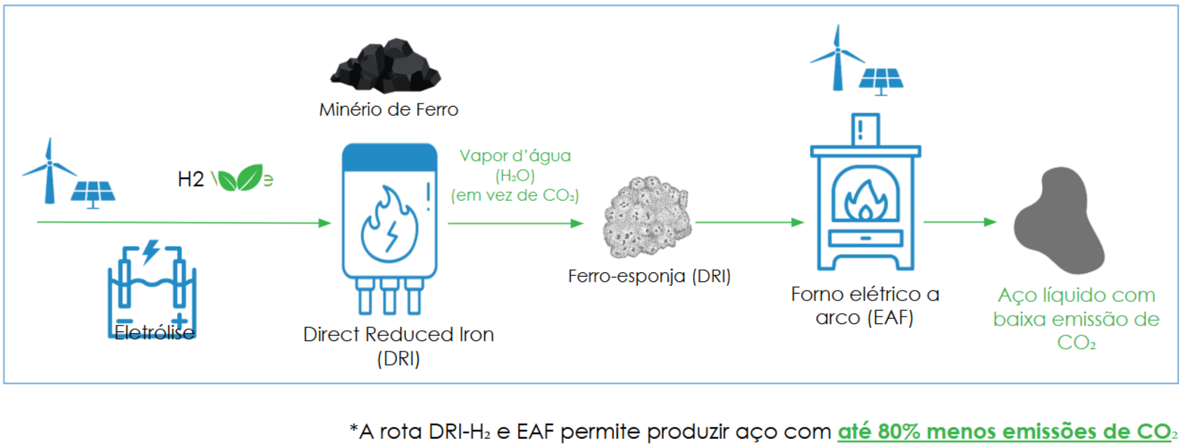
initiatives such as *Clean Hydrogen Alliance and the European Clean Hydrogen Industrial Platform promote* cooperation between governments, companies, and research centers, while the *Innovative Hydrogen Pilot Fund* and the FCH JU finance pilot projects and technological research[18].

2.2 Green steel and *hard-to-abate* sectors: policies and regulatory instruments

The steel sector, in particular, represents a central challenge for climate neutrality[19]Iron and steel production relies heavily on the burning of coal and coke, processes that result in high greenhouse gas emissions. Paradoxically, these same materials are essential for the energy transition, forming the structures of wind turbines, solar panels, and electric vehicles. In other words, they are irreplaceable in the decarbonization of the economy itself.[20].

In this scenario, green hydrogen emerges as a promising alternative for the production of so-called "green steel." By replacing fossil-based carbon as a reducing agent and energy source in electric blast furnaces, this technology enables a significant reduction in greenhouse gas emissions from the steel industry.

Figure 01 - Green steel production



Source: Own elaboration

As illustrated in Figure 01, hydrogen is obtained by electrolysis of water fed by renewable sources and used in the direct reduction of iron ore (*Direct Reduced Iron – DRI*), releasing only water

[18] LEGGERINI, C.; BANNÒ, M.; DAL MOLIN, M. Hydrogen innovation: An exploration of its determinants across Europe. **Energy Policy**, [S.l.], v. 204, p. 114675, 2025. ISSN 0301-4215. Available at: https://www.sciencedirect.com/science/article/pii/S030142152500182X. Accessed on: July 14, 2025.

[19] OECD, 2025. **Hydrogen in steel**: addressing emissions and dealing with overcapacity. Paris: Organisation for Economic Co-operation and Development. Disponível em: https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/03/hydrogen-in-steel_f4d15f8d/7e2edc69-en.pdAccessed on: July 12, 2025.

[20] YU, S.M.*et al*. Prospect of green hydrogen in Malaysian iron and steel industry: techno-economic assessment and energy modelling using PyPSA-Earth. **Renewable and Sustainable Energy Reviews**, v. 216, 2025, art. 115665. ISSN 1364-0321. Available at: https://doi.org/10.1016/j.rser.2025.115665 . Accessed on: July 8, 2025.

vapor (H_2O) instead of carbon dioxide (CO_2). The resulting product, known as sponge iron, is then melted in an electric arc furnace (*Electric Arc Furnace – EAF*), also powered by renewable electricity, to produce low-carbon liquid steel. This technological approach, called DRI–H_2 + EAF, reduces CO_2 emissions associated with steel production by up to 80% compared to conventional methods based on blast furnaces and oxygen converters, representing a promising path toward decarbonizing the steel sector.[21].

European policies already recognize this potential and are beginning to direct regulatory and financing instruments. Infrastructure development, support for technological innovation, and the definition of clear standards for green hydrogen, such as certifications, are fundamental steps toward making the large-scale transition viable.[22].

3 EUROPEAN TAXONOMY AND CRITERIAELIGIBILITYFOR GREEN HYDROGEN

3.1 RED II / RED III and renewable energy certification

The European taxonomy for green hydrogen is based on strict eligibility criteria that ensure its sustainable production and alignment with the European Union's climate goals.

One of the central concepts is that of RFNBO[23] (*Renewable Fuels of Non-Biological Origin*). In the case of hydrogen, this means green hydrogen—produced by water electrolysis using only electricity from renewable sources, without any use of biomass or fossil fuels. Furthermore, to be classified as RFNBO, this hydrogen must have its origin and production chain fully traceable, in accordance with established environmental standards and criteria.[24]

The Renewable Energy Directive (RED II), adopted in 2018 by the European Union, established targets for the incorporation of renewable fuels of non-biological origin (*Renewable Fuels of Non-Biological Origin – RFNBOs*) in the transportation sector and industry. Although green hydrogen is not strictly a "fuel" in the traditional sense—it is an energy input that can be used as a raw material, energy carrier, or reducing agent.

Under RED II, by 2030, at least 1% of total energy consumed in transportation and 42% of hydrogen used in industry should come from RFNBOs. In 2023, RED III expanded these targets, setting a 29% share of renewable energy in the transportation sector and introducing specific sub-targets for different fuels, with incentive mechanisms (*multipliers*). Among them, multipliers of up to 4 times for

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21 AJANOVIC, A.; SAYER, M.; HAAS, R. On the future relevance of green hydrogen in Europe. **Applied Energy**, [S.l.], v. 358, p. 122586, 2024. ISSN 0306-2619. Available at: https://www.sciencedirect.com/science/article/pii/S0306261923019505. Accessed on: July 14, 2025.

22 AJANOVIC, A.; SAYER, M.; HAAS, R. On the future relevance of green hydrogen in Europe. **Applied Energy**, [S.l.], v. 358, p. 122586, 2024. ISSN 0306-2619. Available at: https://www.sciencedirect.com/science/article/pii/S0306261923019505. Accessed on: July 14, 2025.

23 PANOUTSOU, C. *et al*. Advanced biofuels to decarbonise European transport by 2030: Markets, challenges, and policies that impact their successful market uptake. **Energy Strategy Reviews**, v. 34, p. 100633, 2021. Available at: https://www.sciencedirect.com/science/article/pii/S2211467X21000195. Accessed on: August 18, 2025.

24 R3 SUSTAINABILITY. **How RFNBO Compliant Hydrogen Is Shaping the Future of Renewable Energy**.April 3, 2025. Available at: https://r3sustainability.com/how-rfnbo-compliant-hydrogen-is-shaping-the-future-of-renewable-energy/ . Accessed on: July 22, 2025.

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renewable electricity used in road vehicles and 1.5 for rail transport[25]. RED III also consolidated the role of RFNBOs in conjunction with advanced biofuels, establishing that both must represent, at a minimum, 5.5% of the transportation sector's energy matrix, with at least 1% coming specifically from RFNBOs. This approach reinforces the importance of renewable energy certification, ensuring sustainability and traceability as pillars of the European energy transition.[26]

3.2 Requirements for additionality, temporality and geolocation of renewable electricity

To be considered RFNBO *compliant*, that is, in line with the regulatory criteria of the European Union, hydrogen must meet a strict set of requirements defined by Delegated Regulation (EU) 2023/1184 and the RED II and RED III directives.

First, the electricity used to produce hydrogen must be 100% renewable. The European Commission requires that this energy come from sources that do not generate carbon emissions, thus ensuring the fuel's sustainability. Furthermore, there must be additionality, that is, proof that hydrogen production has driven the installation of new renewable capacity; the generating source must have been activated up to 36 months before the start of hydrogen production, ensuring that the process does not depend on renewable energy already existing and in use[27]. Another important aspect is the temporal correlation, which requires renewable electricity generation and hydrogen production to occur simultaneously, initially within the same month and, starting in 2030, at the same time. This rule prevents the use of stored or offset renewable energy at different times, promoting transparency and accuracy in green hydrogen certification.[28] A geographic correlation requires that the renewable electricity used be generated in the same electrical zone as the electrolyzer or in interconnected areas with similar prices, ensuring that hydrogen is produced under conditions close to real renewable generation, reinforcing its environmental legitimacy[29]. Finally, for

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[25] SCHMIDT, J. *et al*. The EU additionality rule does not guarantee additionality. **Joule**, [S.l.], v. 8, n. 3, p. 553–556, 2024. ISSN 2542-4351. Available at:https://www.sciencedirect.com/science/article/pii/S2542435124000588. Accessed on: July 15, 2025.

[26] R3 SUSTAINABILITY. **How RFNBO Compliant Hydrogen Is Shaping the Future of Renewable Energy**.April 3, 2025. Available at: https://r3sustainability.com/how-rfnbo-compliant-hydrogen-is-shaping-the-future-of-renewable-energy/. Accessed on: July 22, 2025.

[27] EUROPEAN UNION. Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin. **Official Journal of the European Union**, L 157, p. 11–19, June 20, 2023. Available at:http://data.europa.eu/eli/reg_del/2023/1184/oj . Accessed on: July 17, 2025.

[28] EUROPEAN UNION. Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin. **Official Journal of the European Union**, L 157, p. 11–19, June 20, 2023. Available at:http://data.europa.eu/eli/reg_del/2023/1184/oj. Accessed on: July 17, 2025.

[29] EUROPEAN UNION. Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin. **Official Journal of the European Union**, L 157, p. 11–19, June 20, 2023. Available at:http://data.europa.eu/eli/reg_del/2023/1184/oj. Accessed on: July 17, 2025.

hydrogen to be certified as RFNBO, producers must submit detailed documentation demonstrating compliance with all these rules, including the source of electricity, the operation of the facilities, and compliance with additionality and temporal and geographic correlation criteria. These requirements apply to hydrogen produced both inside and outside the European Union, aligning with the RePowerEU plan to promote green hydrogen trade.[30] Ultimately, RFNBO hydrogen is the most rigorous green hydrogen standard, ensuring transparency, traceability, and a real impact on the expansion of renewable sources, contributing decisively to the decarbonization of the industrial and energy sectors.

3.3 Verification and traceability mechanisms

The traceability and verification of green hydrogen classified as RFNBO is not only ensured by a set of regulatory mechanisms but also with a certification system recognized by the European Commission. It is important to highlight that, regardless of whether hydrogen is produced inside or outside the European Union, producers can use either the national certification systems of the member states or the voluntary international certification systems approved by the European Commission to demonstrate compliance with the required technical and environmental criteria.[31]

Systems like *REDcert-EU* play an essential role in certifying the hydrogen production chain. The scope of certification can vary depending on the producer's organizational structure and may cover individual facilities (such as electrolysis) or composite systems (which integrate electrolysis, carbon capture, and fuel production on the same site). In both cases, the establishment of a mass balance system and the individual calculation of greenhouse gas (GHG) emissions are mandatory, according to a standardized methodology.[32]

Furthermore, the raw material origin points must be certified, individually or by group, with periodic inspections carried out by recognized certification bodies. Compliance can be demonstrated through signed declarations and neutral audits. Responsible auditors must have proven experience in fuel life cycle assessment, emissions auditing, and technical knowledge of applicable regulations.[33] These mechanisms ensure not only the environmental credibility of RFNBO hydrogen but also its

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[30] EUROPEAN UNION. Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin. **Official Journal of the European Union**, L 157, p. 11–19, June 20, 2023. Available at:http://data.europa.eu/eli/reg_del/2023/1184/oj. Accessed on: July 17, 2025.

[31] EUROPEAN UNION. Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin. **Official Journal of the European Union**, L 157, p. 11–19, June 20, 2023. Available at:http://data.europa.eu/eli/reg_del/2023/1184/oj. Accessed on: July 17, 2025.

[32] REDCERT. **REDcert – Certification systems for sustainable biomass, biofuels and bioliquids**.Available at: https://www.redcert.org/en/ . Accessed on: July 22, 2025.

[33] EUROPEAN UNION. Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin. **Official Journal of the European Union**, L 157, p. 11–19, June 20, 2023. Available at:http://data.europa.eu/eli/reg_del/2023/1184/oj. Accessed on: July 17, 2025.

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acceptance in international markets by guaranteeing complete traceability, data standardization, and the integrity of certification processes.

4 THE BRAZILIAN REGULATORY FRAMEWORK FOR LOW-EMISSION HYDROGEN

4.1 Analysis of Law No. 14,993/2024 ("Fuels of the Future Bill")

Enacted on October 24, 2024, Law No. 14.993/2024, known as the "Fuels of the Future Bill," represents a milestone in the consolidation of Brazil's energy transition by establishing guidelines for the promotion of low-carbon fuels and associated infrastructure, with special attention to low-emission hydrogen. This law not only integrates but also complements the legal framework established by Law No. 14.948/2023 (the Hydrogen Legal Framework). This regulatory ambition reflects the legislative effort to align Brazil with global decarbonization commitments.[34]

Notable among its innovations is the inclusion of Section XIX in Article 1 of Law No. 9,478/1997, which expressly recognizes the objective of national energy policy as stimulating production, competitiveness, and attracting investment in the low-carbon hydrogen industry and its derivatives. Furthermore, the Law strengthens the role of the National Agency of Petroleum, Natural Gas, and Biofuels (ANP) by modifying Section VIII of Article 8, granting it the authority to declare areas designated for hydrogen infrastructure as public utilities. Furthermore, the new Sections XXXVI to XXXVIII of the same article expand the ANP's responsibilities, authorizing it to regulate and monitor various stages of the hydrogen supply chain, such as production, transportation, marketing, and storage. This legislative framework also establishes three national programs: the National Sustainable Aviation Fuel Program (ProBioQAV), the National Green Diesel Program (PNDV), and the Biomethane Incentive Program, establishing progressive targets for incorporating these fuels into the energy mix. In this context, hydrogen gains relevance not only as an energy vector but also as a strategic input in industrial processes and in the decarbonization of the transportation sector. The law also recognizes the importance of carbon capture and geological storage (CCS) as a complementary measure for emissions reduction, a particularly relevant aspect for the viability of blue hydrogen.[35]

Despite regulatory advances, the law's effectiveness depends on overcoming structural obstacles, such as the lack of logistical infrastructure and the absence of a regular supply of renewable fuels, as evidenced by the law's enactment event, in which a flight carrying SAF was canceled due to a lack of fuel at the airport. This episode illustrates the need for robust regulatory planning capable of providing legal certainty

[34] VELOSO, Isabel; IZIDORO, Leonardo. **O voo inicial da lei dos 'combustíveis do futuro'**. BrasilAgro, 16 out. 2024. Disponível em: https://www.brasilagro.com.br/conteudo/o-voo-inicial-da-lei-dos-combustiveis-do-futuro-.html . Acesso em: 04 ago. 2025.

[35] CLIMATE OBSERVATORY. **Future of energy**: Climate Observatory's vision for a just transition in Brazil. October 2024. [PDF]. Available at: https://www.oc.eco.br/wp-content/uploads/2024/10/OC_Futuro-da-Energia.pdf . Accessed on: August 4, 2025.

and attracting investments on a scale commensurate with the challenges of the national energy transition.[36]

4.2 Institutional certification and governance instruments (ANP)

The consolidation of low-emission hydrogen in Brazil depends not only on the creation of legal frameworks, but also on the implementation of effective certification instruments and the structuring of robust regulatory governance. In this sense, Law No. 14,948/2024 assigns the National Agency of Petroleum, Natural Gas, and Biofuels (ANP) a central role in this process, granting it broad powers, such as authorizing the production, transportation, and commercialization of hydrogen and its derivatives, as well as regulating its geological exploration. The ANP may also use mechanisms such as *a sandbox regulatory* framework and pilot projects, while developing specific regulations for the sector. However, the scope of these responsibilities contrasts with the challenges faced by the agency, such as budget constraints and staff shortages, which could compromise the effectiveness and speed of implementing the new legal framework.[37] In the field of certification, still in its infancy in Brazil, initiatives such as that of the Electric Energy Trading Chamber (CCEE), which issues certificates for hydrogen produced from renewable sources, signal progress. However, to enable international trade in green hydrogen derivatives, such as ammonia and methanol, it will be necessary to develop certification schemes compatible with international standards, promoting interoperability between jurisdictions. This regulatory challenge adds to barriers already identified in the adoption of other renewable energies in Brazil, such as solar photovoltaics, where high upfront costs, bureaucracy, and lack of local incentives still hinder technological diffusion.[38] According to the International Renewable Energy Agency (IRENA), standardization and certification are essential to ensure the traceability and sustainability of hydrogen value chains, in addition to reducing regulatory risks and facilitating investment.[39] In this context, the institutional governance of green hydrogen is still developing. The ANP is part of the National Hydrogen Program Steering Committee (Coges-PNH2), but inter-institutional coordination and a clear definition of roles among the different agencies involved require improvement[40]. Building an efficient regulatory framework, with transparent and internationally recognized certification schemes, will be crucial for Brazil to integrate into global hydrogen markets and achieve its climate goals. In this regard,

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[36] VELOSO, I.; IZIDORO, L. **O voo inicial da lei dos 'combustíveis do futuro'**. BrasilAgro, 16 out. 2024. Disponível em: https://www.brasilagro.com.br/conteudo/o-voo-inicial-da-lei-dos-combustiveis-do-futuro-.html . Acesso em: 04 ago. 2025.

[37] JOTA. **Brasil dá importante passo para nova era dos combustíveis sustentáveis**. JOTA – opinião e análise, pub. há cerca de 9 meses (nov. 2024). Disponível em: https://www.jota.info/opiniao-e-analise/artigos/brasil-da-importante-passo-para-nova-era-dos-combustiveis-sustentaveis . Acesso em: 04 ago. 2025.

[38] PURIFICAÇÃO, Rafael Alexandre do Nascimento; RAMOS, Heidy Rodriguez; KNIESS, Cláudia Terezinha. Barreiras e facilitadores para o uso da energia fotovoltaica: uma revisão sistemática da literatura. **Fórum Ambiental da Alta Paulista**, v. 16, n. 2, 2020. Disponível em: https://publicacoes.amigosdanatureza.org.br/index.php/forum_ambiental/article/view/2327. Acesso em: 24 set. 2025

[39] NEVES, L. **Padronização e certificação são essenciais para desenvolver mercados de derivados de hidrogênio verde**. pv magazine Brasil, 27 dez. 2024. Disponível em: https://www.pv-magazine-brasil.com/2024/12/27/padronizacao-e-certificacao-sao-essenciais-para-desenvolver-mercados-de-derivados-de-hidrogenio-verde/ . Acesso em: 04 ago. 2025.

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the decentralization of environmental policies has already shown positive results in national experiences, such as the Green-Blue Municipality Program, which highlights the role of municipalities in integrated governance for sustainability.[41]

5 CASE STUDY: THE GERMAN REGULATORY MODEL FOR GREEN HYDROGEN

5.1 Germany's National Hydrogen Strategy (Nationale Wasserstoffstrategie)

Germany, the largest industrial power in the European Union and the country with the largest fiscal space in the bloc, has invested strategically in the development of a hydrogen economy, positioning itself as a global supplier of technologies and a major importer of green hydrogen.[42]

In July 2023, the German government approved an update to its National Hydrogen Strategy (Nationale Wasserstoffstrategie – NWS), originally launched in 2020, to adapt it to recent developments in the energy and climate landscape. The update reaffirms Germany's commitment to decarbonization and energy security, expanding the role of green hydrogen as a key enabler in the energy transition.[43]

The new strategy establishes six main goals by 2030: (1) Stimulate the domestic market for hydrogen and its derivatives, promoting the acceleration of technologies and applications along the value chain; (2) Ensure the availability of hydrogen, increasing the installed electrolysis capacity target from 5 GW to at least 10 GW, with the remainder supplied by imports. A specific import strategy is under development; (3) Develop an efficient infrastructure, reusing existing gas pipelines and building new routes integrated into the European backbone, totaling approximately 4,500 km. The goal is to connect all production, import, and storage centers to consumers by 2030; (4) Implement the use of hydrogen in strategic sectors such as heavy industry, long-distance transportation, aviation, and flexible electricity generation. Hydrogen will also contribute to the security of energy supply; (5) Make Germany a global leader in hydrogen technology, mastering the entire production chain, from the manufacture of electrolyzers to applications such as fuel cells; (6) Create stable and harmonized regulatory conditions at the national, European, and international levels. This includes more efficient technical standards, certifications, and licensing processes.[44] To facilitate imports, Germany has developed its own import strategy and operates the H2Global mechanism, which acts as a bridge between international producers of low-emission hydrogen and European buyers. Through

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[41] DUARTE, João Paulo Pereira; RIBAS, Luiz César; HANAI, Frederico Yuri. Descentralização de políticas públicas para uma gestão ambiental integrada: uma análise do programa Município VerdeAzul. **Fórum Ambiental da Alta Paulista**, v. 20, n. 1, 2024. Disponível em: https://publicacoes.amigosdanatureza.org.br/index.php/forum_ambiental/article/view/5286 Acesso em: 24 set. 2025.

[42] QUITZOW, R.; NUNEZ, A.; MARIAN, A. Positioning Germany in an international hydrogen economy: A policy review. **Energy Strategy Reviews**, v. 53, 2024, 101361. ISSN 2211-467X. Available at:https://doi.org/10.1016/j.esr.2024.101361 . Accessed on: July 17, 2025.

[43] NATIONAL AGENCY OF PETROLEUM, NATURAL GAS AND BIOFUELS – ANP.**Implementation of the Low-Carbon Hydrogen Regulatory Framework in Brazil**.Rio de Janeiro: ANP, 2024. Available at:https://www.gov.br/anp/pt-br/centrais-de-conteudo/publicacoes/relatorios/arquivos/implementacaomarcoregulatoriohidrogenio.pdf . Accessed on: July 17, 2025.

[44] NATIONAL AGENCY OF PETROLEUM, NATURAL GAS AND BIOFUELS – ANP.**Implementation of the Low-Carbon Hydrogen Regulatory Framework in Brazil**.Rio de Janeiro: ANP, 2024. Available at:https://www.gov.br/anp/pt-br/centrais-de-conteudo/publicacoes/relatorios/arquivos/implementacaomarcoregulatoriohidrogenio.pdf. Accessed on: July 17, 2025.

the H2Global foundation and its subsidiary HINT.CO, the country conducts international auctions to purchase derivatives such as ammonia, methanol, and SAF (sustainable aviation fuel), reselling them in Europe with subsidies covering the difference between the purchase and sale prices[45]. The first round, with a budget of €900 million, resulted in import contracts for 259,000 tons of green ammonia between 2027 and 2033, representing more than 10% of the country's annual ammonia production. Production costs are around €4.50 per kg of green hydrogen.[46]

These long-term contracts provide investment security to exporters and predictable access to green derivatives for European buyers, stimulating the global growth of the hydrogen industry.

5.2 Certification, supply contracts and demand stimulus instruments

In the German context, green hydrogen certification is considered a central element in ensuring reliability and access to international markets. The federal government requires imports to be accompanied by internationally recognized certificates, which demonstrate compliance with maximum emissions limits (such as the 3.4 kg CO_2-eq/kg H_2 in the EU) and sustainability criteria[47].

To achieve this goal, organizations such as TÜV SÜD, with international operations, offer dual certification, both with their own seal (SCS70) and with the European CertifHy standard, which allows producers to obtain two certifications in a single audit, increasing their competitiveness[48].

In the field of supply contracts, Germany implements mechanisms such as H2Global, which acts as an intermediary buyer, guaranteeing long-term contracts with stable prices for imports, reducing the risk for foreign investors[49]. Demand stimulus instruments are varied, including the Climate Protection Agreements (KSV), IPCEI Hydrogen, Federal Financing for Industry and Climate Protection, in addition to the application of the minimum renewable quotas provided for in RED III[50]. These three types of mechanisms - certification, supply contracts and demand stimulus instruments - ensure a predictable and expanding internal market, promoteing demand and strengthening the entire low-carbon hydrogen value chain.

[45] NATIONAL AGENCY OF PETROLEUM, NATURAL GAS AND BIOFUELS – ANP.**Implementation of the Low-Carbon Hydrogen Regulatory Framework in Brazil**.Rio de Janeiro: ANP, 2024. Available at:https://www.gov.br/anp/pt-br/centrais-de-conteudo/publicacoes/relatorios/arquivos/implementacaomarcoregulatoriohidrogenio.pdf. Accessed on: July 17, 2025.

[46] NATIONAL AGENCY OF PETROLEUM, NATURAL GAS AND BIOFUELS – ANP.**Implementation of the Low-Carbon Hydrogen Regulatory Framework in Brazil**.Rio de Janeiro: ANP, 2024. Available at:https://www.gov.br/anp/pt-br/centrais-de-conteudo/publicacoes/relatorios/arquivos/implementacaomarcoregulatoriohidrogenio.pdf. Accessed on: July 17, 2025.

[47] GERMANY. **The National Hydrogen Strategy**.The Federal Government, 2025. Disponível em:https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Wasserstoff/Dossiers/wasserstoffstrategie.html . Accessed on: July 17, 2025.

[48] GALE, F. *et al*. Renewable hydrogen standards, certifications, and labels: A state-of-the-art review from a sustainability systems governance perspective. **International Journal of Hydrogen Energy**, v. 59, p. 654-667, 2024. Available at:https://doi.org/10.1016/j.ijhydene.2024.02.038 . Accessed on: July 17, 2025.

[49] GERMANY. **The National Hydrogen Strategy**.The Federal Government, 2025. Disponível em:https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Wasserstoff/Dossiers/wasserstoffstrategie.html. Accessed on: July 17, 2025.

[50] GERMANY. **The National Hydrogen Strategy**.The Federal Government, 2025. Disponível em:https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Wasserstoff/Dossiers/wasserstoffstrategie.html. Accessed on: July 17, 2025.

5.3 International cooperation with producing countries

International cooperation is a key pillar of the German strategy for developing the green hydrogen economy, recognizing that most domestic and European demand will depend on imports.[51]

Germany maintains a consolidated network of bilateral energy partnerships, particularly with countries in the Middle East, North Africa, Sub-Saharan Africa, and Central Asia, focused on the energy transition and joint development of the hydrogen sector, distinguishing itself from other powers whose energy relations are still closely linked to fossil fuels and nuclear power. To strengthen this cooperation, the German government has established hydrogen offices (H2 Diplo) in strategic countries such as Saudi Arabia, Angola, Nigeria, Kazakhstan, and Ukraine, expanding political and economic dialogue on hydrogen.[52]

In the multilateral sphere, Germany leads initiatives such as the G7 *Hydrogen Action Pact and* is the founder of the Green *Hydrogen Catalogue of* the UN, promoting global commitments to sustainability and expanding the green hydrogen market. During its presidency of the European Council, Germany promoted important projects (IPCEI) for hydrogen technologies and systems in the EU, as well as regional agreements, such as the Esjberg Declaration with Belgium, Denmark, and the Netherlands for the joint development of offshore wind and hydrogen production in the North Sea.[53].

Germany also has a strong presence in research and innovation, fostering international collaborations with developed and emerging countries, including Australia, Ukraine, Namibia, South Korea, Japan, and Canada. Notable financial support for R&D projects in low- and middle-income countries, such as the €40 million commitment to Namibia, and internal initiatives to attract foreign researchers[54]. Furthermore, Germany promotes the expansion of global supply chains through relevant investments (around €11 billion in the EU via IPCEI) and specific programs such as the International *Hydrogen Ramp Up (H2Uppp)* to support small projects in emerging markets. The most notable program is H2Global, which operates through auctions to secure long-term contracts for the purchase of hydrogen and its derivatives, guaranteeing prices and reducing risks for international producers.[55]

It is interesting to note that this import-oriented and competitive approach contrasts with the

[51] QUITZOW, R. *and has*l. Positioning Germany in an international hydrogen economy: A policy review. **Energy Strategy Reviews**, v. 53, 2024, 101361. ISSN 2211-467X. Available at:https://doi.org/10.1016/j.esr.2024.101361. Accessed on: July 17, 2025.

[52] QUITZOW, R. *et al*. Positioning Germany in an international hydrogen economy: A policy review. **Energy Strategy Reviews**, v. 53, 2024, 101361. ISSN 2211-467X. Available at:https://doi.org/10.1016/j.esr.2024.101361. Accessed on: July 17, 2025.

[53] QUITZOW, R. *et al*. Positioning Germany in an international hydrogen economy: A policy review. **Energy Strategy Reviews**, v. 53, 2024, 101361. ISSN 2211-467X. Available at:https://doi.org/10.1016/j.esr.2024.101361. Accessed on: July 17, 2025.

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[55] QUITZOW, R. *et al*. Positioning Germany in an international hydrogen economy: A policy review. **Energy Strategy Reviews**, v. 53, 2024, 101361. ISSN 2211-467X. Available at:https://doi.org/10.1016/j.esr.2024.101361. Accessed on: July 17, 2025.

strategies of countries like Japan, which invest directly in specific hydrogen transportation and storage technologies.

6 BRAZIL-EU REGULATORY COMPATIBILITY: OBSTACLES AND OPPORTUNITIES

The global energy transition establishes a new arena of international competition and cooperation, in which regulatory compatibility becomes a determining factor for market access and investment attraction. A comparative analysis of the European Union (EU) regulatory framework—which acts as a standard-setter for green hydrogen (H_2V) — and the emerging regulatory framework in Brazil reveals a panorama of significant challenges and strategic opportunities.

6.1 Diagnosis of Brazilian technical and regulatory barriers

Brazil's effective entry into the global H_2V market, especially in Europe, depends on overcoming barriers that transcend mere production capacity. The diagnosis points to a fundamental misalignment between the Brazilian regulatory framework and European eligibility criteria, notably those defining renewable fuel of non-biological origin (RFNBO).

The main regulatory barrier lies in the lack of a national hydrogen certification system that is interoperable with EU standards. While the European bloc, through the RED II and RED III directives and Delegated Regulation (EU) 2023/1184, has established a set of mandatory rules, Brazil still operates with an incipient legal framework (Laws No. 14,993/2024 and No. 14,948/2024) that delegates the development of these mechanisms to the ANP. The lack of a national methodology for mass balance, and for calculating greenhouse gas (GHG) emissions throughout the value chain, prevents verification of Brazilian product compliance.

This gap results in specific technical misalignments with European criteria:

1. **Additionality:** EU regulations require that H_2V production stimulate the addition of new renewable energy generation capacity, installed no more than 36 months before the electrolyzer begins operating. The Brazilian framework, while encouraging renewable energy, does not establish a direct and verifiable link between a hydrogen project and the addition of new electricity capacity, which constitutes a direct obstacle to RFNBO certification.
2. **Temporal Correlation:** The temporality criterion, which determines the simultaneity between renewable electricity generation and consumption by the electrolyzer (monthly until 2029, hourly from 2030 onward), requires highly granular energy tracking and management systems. The Brazilian National Interconnected System (SIN) metering infrastructure and regulation were not designed for this level of contractual traceability, representing a significant technical and market barrier.
3. **Geographic Correlation:** The requirement that production occur in the same "electrical zone" as renewable generation (or in interconnected zones with correlated electricity prices) presents challenges in transposing it to the reality of the Brazilian electricity system, whose submarkets are broad and diverse. The definition of bidding zones compatible with the European model is still under debate and has not been implemented.

Additionally, institutional governance, although designed with the centrality of the ANP in mind, faces challenges in terms of technical and budgetary capacity to develop, implement, and monitor such a complex regulatory system in a timely manner to capture the market's window of opportunity.

6.2 Market Exclusion Risks Versus Incentives for Regulatory Convergence

The divergence between the Brazilian and European regulatory systems engenders a duality of forces: the imminent risk of exclusion from strategic markets and, paradoxically, a powerful incentive for convergence and modernization.

The main risk arises from the so-called “Brussels Effect”[56]: producers of H_2V and its derivatives, such as green ammonia and methanol, who fail to demonstrate compliance with the RFNBO criteria will not be able to count towards the mandatory targets for the EU transport and industrial sectors. Consequently, these products would be relegated to markets with lower added value or without specific demand for certified sustainability, compromising the economic viability of export projects and reducing returns on investments. Mechanisms such as Germany's H2Global, which ope rate based on strict sustainability criteria aligned with those of the EU, would become inaccessible to non-certified Brazilian producers. This scenario poses a risk of stranded assets (idle assets) for investments already announced in Brazil.

On the other hand, the rigidity of the European framework functions as an "exogenous driver" for regulatory convergence. The need to align with international standards to compete puts pressure on Brazil to: (i) Accelerate the development of its regulatory framework: The demand for certification forces the State and market agents to rapidly develop the necessary standards, traceability systems, and institutional capacity; (ii) Attract qualified capital: Adherence to international sustainability and transparency standards increases legal certainty and makes Brazilian projects more attractive to international investors and development agencies, which often condition financing on compliance with strict ESG (Environmental, Social and Governance) criteria; and (iii) Creating an exportable "gold standard": By developing a certification system that is compatible with the world's most demanding model (the European), Brazil positions itself to access not only the EU but also other developed markets, such as Japan[57] and South Korea[58], which tend to adopt similar standards. Convergence, therefore, is not just an obligation but a global competitive positioning strategy.

6.3 Opportunities for the green steel industry in Brazil as a vector for value addition

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[56] The term *Brussels Effect* describes the phenomenon by which non-EU partners end up adapting to its regulations, not only to maintain access to a large-scale market, but also because this means aligning themselves with some of the world's most stringent standards and norms, which tend to be standardized across global markets. See: Bradford, A.**The Brussels Effect**: How the European Union Rules the World. Oxford University Press, 2020.

[57] EUROPEAN UNIONUNIÃO EUROPEIA. **EU-Japan Memorandum of Cooperation on Hydrogen**. Directorate-General for Energy, 2 dez. 2022. Disponível em: energy.ec.europa.eu/publications/eu-japan-memorandum-cooperation-hydrogen_en. Acesso em: 18 ago. 2025.

[58] KUSTOVA, I. et al. **From partnership to leadership**: energising EU–Korea cooperation on the road to net zero. CEPS In-Depth Analysis. Brussels: Centre for European Policy Studies (CEPS), May 2025. Disponível em: cdn.ceps.eu/wp-content/uploads/2025/05/CEPS-Korea-report-2025-formatted.pdf. Acesso em: 18 ago. 2025.

Regulatory convergence for H_2V transcends the energy sector, enabling transformative opportunities for national industry, particularly the steel industry. The production of "green steel" represents the clearest vector for value addition in the hydrogen chain, allowing Brazil to leverage its unique comparative advantages.

The country holds a privileged position by concentrating, in its territory, two essential inputs for the production of green steel through the technological route of direct reduction with hydrogen (DRI-H_2) followed by an electric arc furnace (EAF): high-quality iron ore and one of the largest potentials for low-cost renewable energy generation in the world.

The opportunity consists of internalizing stages of the value chain, shifting from exporting low-value-added commodities (iron ore) to producing and exporting a very high-value industrial product (green steel). This transition represents a strategic reindustrialization movement based on cutting-edge technology and sustainability, with multiple benefits:

- **Economic:** Creation of highly skilled jobs, increased revenue, attraction of investments in modern industrial plants, and strengthening of the trade balance through a product with a sustainability premium.
- **Strategic:** Positions Brazil not only as a clean energy (H_2V) supplier, but also as an indispensable industrial partner in the decarbonization of hard-to-abate sector on a global scale.
- **Environmental:** It contributes significantly to the country's and the planet's climate goals by decarbonizing one of the most emissions-intensive sectors.

However, the materialization of this opportunity is directly dependent on overcoming the barriers discussed in section 6.1. Steel can only be comarketed as "green" in the European market if the hydrogen used in its production is certified as RFNBO. The absence of a robust certification system aligned with European criteria would nullify the main competitive advantage of the Brazilian product, making it indistinguishable from conventionally produced steel in the eyes of international buyers. Thus, the construction of a regulatory framework for hydrogen is not an end in itself, but a prerequisite. *sine qua non to* unlock the potential of a new green industrialization in Brazil.

7 CONCLUSION

An analysis of the regulatory frameworks of the European Union and Brazil, complemented by a study of the German model, suggests that Brazil's strategic insertion into the emerging global economy of green hydrogen (H_2V) and its derivatives, such as green steel, is inseparable from overcoming a significant regulatory gap. The study demonstrated that, beyond its vast potential in renewable and mineral resources, the country's competitiveness in the international market will be determined by its ability to build a regulatory framework aligned with the rigorous sustainability criteria defined by importing markets, notably the European one. The central thesis, that EU regulation acts as an exogenous driver for the modernization of domestic policies, was corroborated by the identification of critical barriers, such as the lack of a certification system that ensures compliance with additionality, temporality, and traceability requirements. In this context, formulating a regulatory convergence strategy emerges not as an option, but as a prerequisite for realizing export opportunities. Such a strategy requires, first and foremost, the development of internationally credible certification instruments. This implies developing a robust national system, with transparent methodologies for calculating mass balance and carbon footprint, that is interoperable and recognized by voluntary or official schemes accepted by the European Commission. The credibility of these certificates is the pillar that will guarantee access for Brazilian H_2V and green steel to the European premium market. Second, the analysis highlights the need for cohesive integration between energy, industrial, and environmental regulation. A fragmented approach, in which each policy operates in isolation, proves inadequate for managing the complexity of the H_2V value chain. Sector governance must, therefore, articulate energy transition objectives with sustainable reindustrialization goals and environmental commitments, ensuring that incentives and regulations reinforce each other, creating a predictable and secure business environment for long-term investments. Furthermore, Brazil's progress can be accelerated through bilateral cooperation, particularly the strategic partnership with Germany, and through active participation in multilateral forums. Engagement with Germany, which already has an import mechanism like H2Global, can facilitate technical alignment, accelerate the regulatory learning curve, and create concrete trade channels. At the same time, Brazil's assertive presence in global platforms discussing hydrogen standards is crucial to defending its interests and contributing to the development of rules that recognize the specificities of predominantly renewable energy systems. It follows, therefore, that the transition from a potential exporter to a consolidated supplier of H_2V and high-value-added products requires a clear strategic regulatory vision. This vision transcends the mere enactment of laws and is embodied in the State's role as an institutional coordinator and driver of sustainable industrialization. The State's responsibility is not only to regulate but also to orchestrate the interaction between agencies, the private sector, and international partners, fostering the necessary ecosystem of innovation, infrastructure, and legal certainty. Brazil's establishment as a central player in the global hydrogen economy will depend not only on its natural resources but, crucially, on the architecture of a lucid, integrated regulatory strategy aligned with the demands of the new energy geopolitics.

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DECLARATION

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DECLARATION OF CONFLICTS OF INTEREST

We, Isabel Veloso and Léa Guillaumier, declare that the manuscript entitled *"Between Opportunity and Regulatory Adequacy: Challenges of Brazilian Green Hydrogen in Light of European Union Requirements"* involves no conflicts of interest.

- **Financial Interests:** We have no financial interests that could influence the results or interpretation of this work.

- **Professional Relationships:** We have no professional relationships that could affect the analysis, interpretation, or presentation of the results.

- **Personal Conflicts:** We have no personal conflicts of interest related to the content of the manuscript.