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The Brazil-Germany Energy Partnership: From Nuclear To Green Hydrogen - A Perspective On Mutual Benefits In The Energy Transition Of The 21st Century

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Abstract:
Background: *This study explores the energy relations between Germany and Brazil within the context of the ongoing energy transition. It underscores the importance of international cooperation during this period of rapid climate change and discusses the mutual benefits for both countries resulting from the commercialization of green hydrogen.*
Materials and Methods: *The research adopted a qualitative approach, essential for an in-depth exploration of the strategic relations between Germany and Brazil. The methodology consisted of a literature review, which involved consulting sources categorized into three main groups: (1) global warming and energy transition, (2) the green hydrogen context, and (3) energy relations between Germany and Brazil.*
Results: *The findings highlight the strategic efforts of both countries to strengthen energy relations in the field of green hydrogen. This cooperation reflects a win-win dynamic, with significant mutual benefits in advancing the energy transition and fostering sustainable development.*
Conclusion: *The study concludes that the strategic energy partnership between Germany and Brazil has evolved significantly, from nuclear cooperation in the 20th century to a current focus on green hydrogen production. This partnership represents a key example of international collaboration addressing global energy challenges.*
Keywords: *Energy Transition; International Cooperation; Green Hydrogen; Strategic Relations.*

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I. Introduction

History demonstrates that no state is entirely self-sufficient or fully independent within the global arena. On the contrary, nations seek to fulfill their interests—whether political, economic, social, or scientific-technological—through diplomatic, economic, commercial, academic, bilateral, or multilateral relations with other members of the international community. In their effort to mitigate the environmental impacts of fossil fuels and increase the production of renewable energy during the energy transition process, Brazil and Germany have strategically joined forces in a race against time, fostering a mutually beneficial, win-win relationship.

This study adopted a qualitative methodology, utilizing bibliographic and documentary research as its primary investigative approach. The data collection involved extensive consultation of national and international publications, reports, scientific articles, and online sources. This process allowed for the identification and analysis of the most critical issues related to the topic.

The primary objective of this research is to explore the strategic relations between Germany and Brazil, from nuclear cooperation in the 20th century to the current partnership in green hydrogen production. As an outcome of this energy diplomacy, the study emphasizes how both nations could mutually benefit in the 21st century from the global economy's decarbonization through what is considered the fuel of the future: green hydrogen.

The specific objectives include understanding the causes and reasons driving the energy transition and the global economy's decarbonization, characterizing the global and Brazilian contexts of green hydrogen, outlining agreements between Germany and Brazil in the nuclear sector from the second half of the 20th century, and demonstrating the current partnerships between the two countries regarding green hydrogen, with an emphasis on the mutually beneficial outcomes of this international cooperation.

The article is structured to provide a comprehensive analysis of the strategic energy relations between Germany and Brazil. It begins by introducing the central theme of the study, followed by a description of the research methodology, including data collection and analysis strategies. A theoretical framework is then

presented, addressing the causes and reasons behind the energy transition, the global context of green hydrogen, the historical nuclear cooperation between Germany and Brazil, and the main developments surrounding international cooperation in green hydrogen production. Finally, the study concludes by synthesizing its main findings, highlighting the advantages for both nations arising from the production and use of green hydrogen.

II. Material And Methods

The approach adopted in this research was qualitative in nature, as the primary objective was to understand the complex international relations between Germany and Brazil in the energy sector and their mutual benefits derived from this bilateral cooperation. Qualitative research is widely recognized in the scientific community for its ability to provide contextual analyses, allowing for an evaluation of the current diplomatic-climatic-energy environment. This approach focuses on the interpretation and comprehension of complex phenomena, making it particularly suitable for fields such as international relations, where variables are dynamic and multifaceted.

According to Creswell (2014), qualitative research contributes to the construction of knowledge in areas where social relations, human perceptions, and cultural contexts play essential roles. The research procedure adopted was a literature review, a methodology critical to scientific knowledge construction, as it facilitates a critical and integrated analysis of existing information on a given topic[1].

As noted by Lakatos and Marconi (2017), bibliographic research broadens the understanding of the subject under study and promotes the consolidation of well-founded approaches[2]. For this review, the research sources were carefully selected and classified into three main categories: (1) sources specific to the energy transition, addressing the causes and reasons for the decarbonization of the global economy; (2) sources focused on the context of green hydrogen within the global energy transition; and (3) sources related to energy cooperation between Germany and Brazil, spanning from nuclear collaboration in the 20th century to the current strategic partnership involving green hydrogen.

This classification enabled a more precise and contextualized analysis, facilitating the construction of a robust discussion on the mutual benefits for Germany and Brazil in the production of green hydrogen. The review was conducted through the consultation of reports from international organizations, publications by federal agencies of the German and Brazilian governments, recent scholarly articles, and books, ensuring comprehensive coverage that reflects the most relevant and up-to-date contributions in the field.

III. Literature Review

This theoretical framework was organized into four subtopics. The first addresses the reasons and causes behind the energy transition and the decarbonization of the global economy. The second provides a brief overview of the global and national context of green hydrogen. The third examines nuclear cooperation between Germany and Brazil during the 20th century. Finally, the fourth explores the relationship between the two countries regarding green hydrogen production, highlighting the mutual benefits arising from this international cooperation.

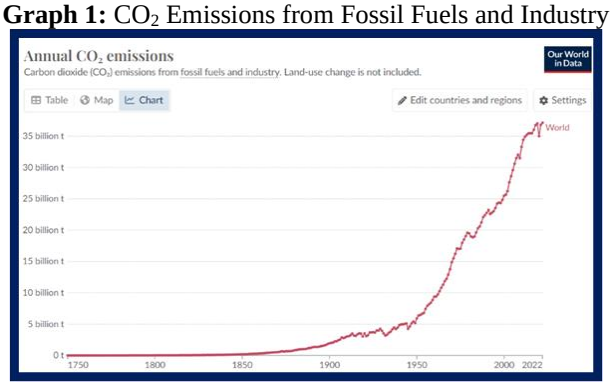
Causes and Reasons for the Energy Transition and Economic Decarbonization

Ecosystems are undergoing profound and rapid transformations across all continents due to the disruptions caused by industrial and energy-related activities. Consequently, there is an observable increase in environmental pollution and the degradation of natural resources, resulting in a high risk of losing conditions necessary for environmental regeneration[3].

This situation has led to the emergence of the term "greenhouse effect," a physical process that stabilizes Earth's temperature, enabling the sustenance of life across various ecosystems. According to the esteemed institution National Geographic (2021), in 1824, French scientist Jean Baptiste Joseph Fourier calculated that the planet would be 15.5 ºC cooler without an atmosphere (the greenhouse effect), making life significantly more challenging[4]. "By the end of the 19th century, Swedish scientist Svante Arrhenius was the first to conclude that burning billions of tons of fossil fuels would add more CO_2 to the atmosphere, consequently resulting in global warming"[5].

A significant turning point occurred during the First Industrial Revolution, which took place between 1760 and 1850. Prior to this period, CO_2 emissions were low until the mid-20th century. From 1950 onwards, following World War II, global emissions surged to 6 billion tons of CO_2 due to fossil fuel combustion, reaching a staggering 37 billion tons by 2022 (Graph 1).

Graph 1: CO_2 Emissions from Fossil Fuels and Industry



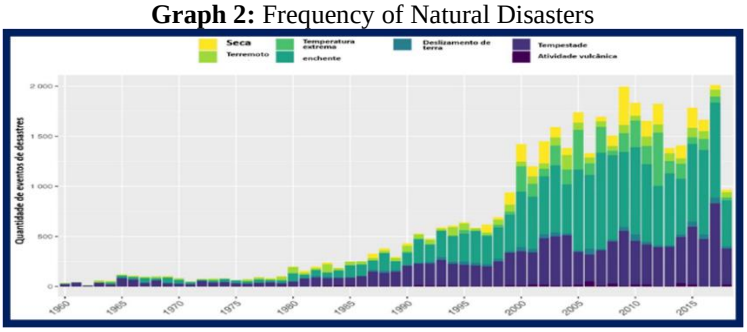
Source: *Our World in Data* (Ritchie; Roser, 2020).

The rapid and disruptive industrial development has been marked by increased emissions of polluting gases, prompting the international community to initiate a race against time to mitigate their effects through an energy transition capable of alleviating global warming and its consequences. In the 1970s, it became evident that excessive consumption of natural resources and intense use of fossil fuels were causing rapid environmental degradation, adversely affecting people's lives. Thus, global warming is a phenomenon whereby heat is retained by the Earth's atmosphere, intensified by the presence of polluting gases resulting from excessive fossil fuel combustion[6], commonly known as greenhouse gases (GHGs).

The emergence of numerous environmental problems and various climatic events are nature's responses indicating that economic activities based on intensive fossil fuel use have reached their limits. If the situation is not reversed, it could lead the planet away from a sustainable society. Extreme natural events have become increasingly frequent, including rising sea levels, widespread droughts, changes in climate patterns, glacial melting, and an increase in the average global temperature[7].

Such occurrences were highlighted in the Intergovernmental Panel on Climate Change (IPCC) report in 2007[5]. Other studies indicate a rise in natural disasters worldwide, establishing a direct correlation between GHG emissions and the increase in global temperatures (Graph 2).

Graph 2: Frequency of Natural Disasters



Source: Lima, Figueiredo and Soares (2022)[8]

Droughts, floods, and temperature extremes are the most evident cases in recent decades. In response to these climatic events, national and international organizations are tirelessly working towards establishing environmental awareness, aiming to reconcile economic activities without compromising natural resources for future generations[3].

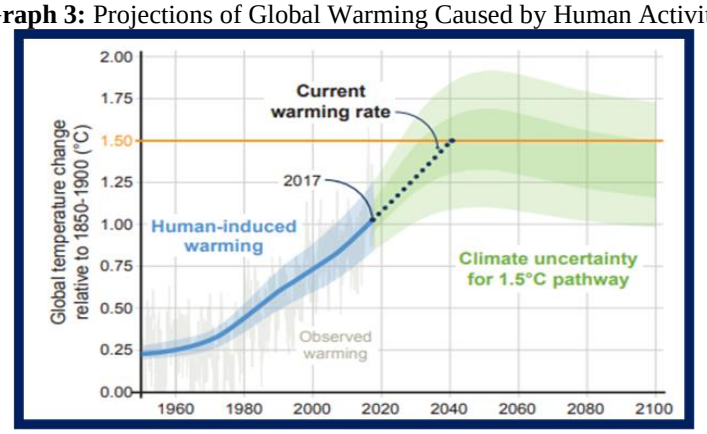
This underscores the imperative need to seek alternative energy generation from renewable sources that are more environmentally clean and ecologically sustainable, in contrast to petroleum-derived fuels. These findings are documented in the 19th Edition of the Global Risks Report 2024, published by the World Economic Forum (WEF), which consolidates various research studies and surveys directed at 1,500 global leaders as well as over 200 thematic experts. One of the conclusions drawn was the acknowledgment of a world plagued by a dangerous climate crisis[9]. In this report, environmental aspects were a concern for two-thirds (66%) of respondents, who classified extreme weather conditions as the highest probability risk for a global crisis in 2024.

Thus, the information corroborates the necessity for countries to implement, with a sense of urgency, an energy transition and decarbonization of their economies, contributing to mitigating the effects of global warming and preventing the emergence of global crises. The National Institute of Meteorology[10] published the report "Global State of Climate" from the World Meteorological Organization (WMO), stating that "the year 2023 is already considered the hottest in 174 years of meteorological measurements." Among other information, the

report presents concerning data, such as the average global temperature over the last ten years being 1.19 ± 0.12°C above the average from 1850 to 1900 (the hottest decade on record); concentrations of carbon dioxide, methane, and nitrous oxide reaching record levels in 2022; ocean heat reaching its highest level in 2022 compared to available data from the last 65 years; and in 2023, average sea levels exceeding those of previous years, reflecting glacial melting[11]. The report from the European Commission's Copernicus Climate Observatory (2024) indicated that in March 2024, average temperatures remained 1.68°C higher than those recorded in March during the pre-industrial era (1850-1900); over the past twelve months, global temperatures were 1.58°C higher than in the pre-industrial era, surpassing the 1.5°C threshold established by the Paris Agreement; and for over a year, ocean temperatures have been warmer than ever before, setting a new historical record with an average surface temperature of 21.07°C[12].

According to the IPCC, human-induced warming reached approximately 1°C above pre-industrial levels in 2017. In Graph 3, if current economic activities based on fossil fuels continue, global temperatures are projected to reach 1.5°C around 2040[13].

Graph 3: Projections of Global Warming Caused by Human Activity



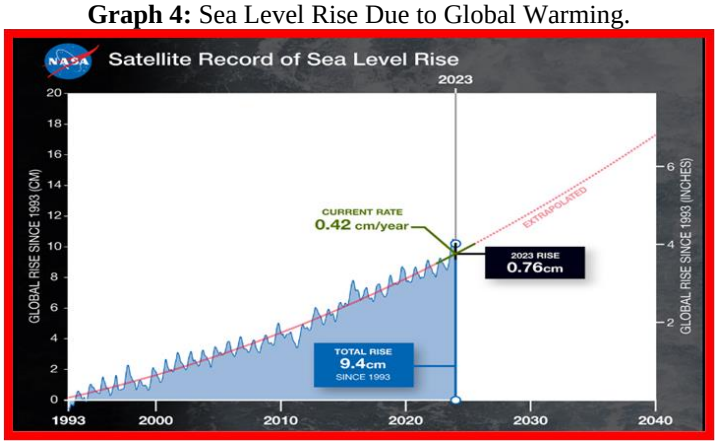
Source: Intergovernmental Panel on Climate Change (2022)[13]

Flooding in coastal areas, increased diseases due to high temperatures, difficulty accessing potable water sources, decreased agricultural production (affected by extreme weather events), rising food prices, among others, are examples of the effects that various cities are facing, leading to disastrous socioeconomic impacts[14].

In March 2024, the U.S. National Aeronautics and Space Administration[15] published an article titled: "Too Hot to Handle: Climate Change May Make Some Places Hard to Live." Based on data collected by satellites, the agency estimated that certain regions of the world could become uninhabitable due to global warming within 30 to 50 years. According to the climate models used, some areas may exceed current temperatures, indicating that the most vulnerable regions would include South Asia, the Persian Gulf, and the Red Sea by around 2050; and Eastern China, parts of Southeast Asia, and Brazil by 2070.

Also in 2024, NASA released scientific data revealing the possibility of a sea-level rise of up to 20 centimeters by 2050. Graph 4 shows the average sea level in blue (1993 to 2023). Future projections indicate that the solid red line would represent the trajectory of this increase (1993 to 2023), which has more than doubled over the last three decades. The dashed red line would project future sea-level rise.

Graph 4: Sea Level Rise Due to Global Warming.



Source: NASA (2024b)[16].

Scientists from the British Antarctic Survey concluded that the melting recorded in Antarctica in 2023 would have been "extremely unlikely" without climate change, with the maximum extent of sea ice decreasing by two million square kilometers. In another finding, studies indicated that climate change has quadrupled the likelihood of such large and rapid melting events[17].

The simultaneous convergence of the aforementioned effects has the capacity to impact millions of people socially and economically. Oliveira (2024, p. 15) summarizes this scenario by stating: "These evidences related to the climate crisis present an imperative to all rational beings inhabiting the planet: the energy transition needs to be intensified, or we risk losing, in a short time frame, the minimum conditions for habitation[27]."

In Germany, faced with the urgency of the energy transition, the government updated its National Security Strategy[18], emphasizing its commitment to combating the climate crisis, declaring that:

The climate crisis threatens the foundations of our lives and our economy. It already has significant repercussions at the security policy level. We will no longer be able to completely avoid the consequences of this crisis; we can only mitigate them.

The Perspective of Green Hydrogen

The previously presented climatic and environmental circumstances, along with the Russia-Ukraine conflict, have made the energy market acutely aware of the importance of renewable energy production, even to ensure greater independence from major coal and oil suppliers[19].

Indeed, the ongoing conflict has compromised the energy security of European economies, leading to significant instability in fossil fuel prices. With a high dependence on Russian fuels, EU countries are seeking solutions to reduce their energy supply reliance[20]. Consequently, governments of potential exporting countries, such as Brazil, are implementing political strategies with many other nations regarding hydrogen at the highest levels of diplomacy[21].

The hydrogen value chain, as an energy vector, is influencing the geography of energy trade, and hydrogen diplomacy is strengthening in various countries.

Global Scenario of Green Hydrogen

Hydrogen, considered the cornerstone of global energy transformation, holds significant importance in various countries, particularly as it offers an alternative in heavily carbonized sectors[22]. This positioning aligns with the report from the United Nations High-Level Political Forum[23] (UN, 2022), which identifies H_2V as a key solution for sectors that are difficult to decarbonize[24].

Among its primary advantages is the decarbonization of sectors such as petrochemicals, iron, steel, and fertilizers. For this reason, global production is expected to grow exponentially in the coming years, with investment figures potentially reaching €500 billion by 2030[25].

Thus, there is strong advocacy in international forums regarding the advantages of H_2V concerning climate issues. According to the International Renewable Energy Agency (IRENA), hydrogen is likely to influence the changing geography of energy trade. As renewable costs decrease, the emerging geopolitical landscape is expected to show increasing regionalization in energy relations. IRENA itself ("The Geopolitics of Energy Transformation: The Hydrogen Factor") points out that countries with abundant low-cost renewable energy could become global producers with geoeconomic consequences due to the competitiveness of production in locations that combine renewable resources, space for solar or wind parks, access to water, and capacity to export to major demand centers[21].

Europe stands out particularly in this scenario. Berger (2023, p. 4) notes that "governments have set decarbonization targets by developing ambitious strategies and goals[25]." Several countries, including Germany, have explicitly mentioned potential hydrogen trade relations in their national strategies[25].

According to Castro et al. (2023), to stimulate economic development, Germany's "National Hydrogen Strategy" introduced an industrial policy aimed at developing the infrastructure necessary for long-term vision[26]. Regarding future outlooks, an action plan focused on the value chain has been established, including innovation and investments[27].

Studies published by the World Energy Council (WEC) indicate that each country tends to adopt its own energy policies without a global standardization. However, there is a consensus: decarbonization of the economy is the primary reason for investing in the hydrogen chain, as illustrated in Table 1 below.

Table 1: European Countries and Their Priorities Related to Hydrogen

Countries	Perspective
Germany	Key industrial sectors prioritizing the use of hydrogen: chemical, petrochemical, and steel industries (focused on heavy vehicles, military vehicles, freight transport, and buses).
France	Carbon-based hydrogen in industrial sectors such as refining, chemicals, agribusiness, naval and aeronautical projects, and electrolyzer production.
Netherlands	Development of infrastructure to meet demand.
Norway	Hydrogen production near consumer markets and CO_2 transport for storage.
Spain	Focus on production and domestic consumption of renewable hydrogen, with long-term export goals.
Portugal	Concentrate on production and domestic use of renewable hydrogen, aiming for long-term export.

Source: WEC (2021)[28].

As European production falls short of its needs, an urgent solution would be the importation from countries where hydrogen could be produced more economically and on a large scale, such as in the Middle East, North Africa, and Latin America[28].

In this context, Germany emerges as an importing country seeking foreign suppliers to ensure its domestic consumption. It is also working to consolidate a global atlas of potential producing countries, enabling future import agreements[28]. In 2021, prospective scenarios were developed by the German Agency for International Cooperation (GIZ), which assessed the potential demand for hydrogen imports for the years 2030 and 2050[29]. See Table 2:

Table 2: Hydrogen Import Demand Scenarios

Parameter	Region	2030		2050	
		Scenario A	Scenario B	Scenario A	Scenario B
Demand for H_2 (TWh)	Germany	4	20	250	800
	European Union	30	140	800	2250

Source: Hebling et al. (2019)[30]

In alignment with the WEC, Bezerra (2023) emphasized that many European countries will not be able to implement the energy transition without resorting to the importation of large volumes of renewable energy[31]. This same observation was made by the Port of Rotterdam (Netherlands), which stated that the importation of green hydrogen will be essential for Europe, as consumption exceeds production[32].

In this context, regions with the capacity to produce renewable energy at low cost would be more competitive in establishing green hydrogen plants aimed at export. Thus, international cooperation emerges as a strategic advantage in strengthening the hydrogen market. Studies from BNDES (2022) indicate that for hydrogen to fulfill its significant role as a decarbonization vector, an exponential increase in global production capacity would be necessary[33].

Finally, the large-scale development of hydrogen worldwide has the potential to create a new industrial sector (production of high-tech equipment). Supply chains and manufacturing of equipment (such as electrolyzers and fuel cells) could generate opportunities and jobs[34]. Therefore, this presents a substantial opportunity for Brazil to become a global energy solution provider (global player).

Brazilian Scenario of Green Hydrogen

Estimates from the Hydrogen Council indicate that Brazil is positioned to become a key player in the green hydrogen (H_2V) market, which is expected to reach a global value of $2.5 trillion by 2050[35]. On one hand, Brazil's competitive advantages include the availability of renewable resources at lower prices; on the other hand, there is a demand from countries like Germany, which has formed partnerships with various nations to develop cooperative activities[26].

The opportunity arises precisely due to European investments, positively reflecting on Brazil's trade balance. As Germany is unable to produce hydrogen in the necessary quantities, the solution would be to source it from countries with production and export capacity, including Brazil, which has abundant solar and wind energy resources[29].

In the report "Update on the Hydrogen Market in Latin America," Brazil is poised to take a prominent position and become one of the leading exporters of hydrogen fuel due to its abundance of renewable energy sources[36], thereby having the opportunity to play a significant international role by facilitating the domestic market and exporting surplus to Europe[24].

As Oliveira (2022) confirms, Brazil holds a prominent position to become a major exporter of low-carbon hydrogen due to its favorable climatic conditions for generating electricity from wind and solar sources. Studies indicate that producing green hydrogen from these sources would represent an opportunity for sustainable socioeconomic development, given the low generation costs and well-located ports in relation to European markets[29].

Brazil's geographical conditions provide it with high capacity for wind and solar energy generation, ranking among the largest in the world. Its solar energy potential is comparable to that of desert countries, and it is also one of the best places globally for producing wind energy[37]. Internationally, Brazil has attracted attention from foreign governments as the National Energy Policy Council identified "hydrogen as one of the priority themes for research and development (R&D) in the country, aiming at resource application"[38].

This declaration followed the publication of the National Energy Plan (PNE 2050) in 2020, which identified hydrogen as a disruptive technology of interest in the context of decarbonizing Brazil's electricity matrix[38].

A year later, Brazil established a strategy for actions related to developing a hydrogen economy through the National Hydrogen Program (PNH2), under the responsibility of the Ministry of Mines and Energy (MME). According to the Triannual Work Plan 2023-2025[22], a competitive advantage was highlighted due to establishing hydrogen production plants in port complexes that include industrial facilities; a similar conclusion was presented by Vasileva (2023)[36].

The understanding is that within a port complex, several factors would combine for developing the H2V chain, such as logistics, proximity to industrial hubs, and renewable energy sources used in hydrogen electrolysis. It is believed that this strategy, already implemented in several countries, would be crucial for enabling a hydrogen economy by fostering investments in energy infrastructure. In Brazil, current port complexes with this profile are located in Pecém-CE, Suape-PE, Açu-RJ, and Rio Grande-RS[29].

Thus, the perspective is to consolidate these hubs in Brazil by 2035 with the aim of catalyzing hydrogen development and production while integrating necessary infrastructures from production stages through storage, transport, and consumption[22]. Once again, Brazil emerges in this competitive scenario as its hydrogen would be obtained from renewable energies (solar and wind) at lower costs compared to other foreign regions. According to the President of Vestas for Latin America, a multinational company in the wind sector:

Green hydrogen can be the main accelerator of increased demand for renewable energies. The electrolysis process consumes a lot of energy—70% of green hydrogen's cost comes from electricity. Brazil has privileged winds, an extensive coastline, excellent climatic conditions, low energy costs, and consequently an extremely competitive cost structure—the lowest in the world[39].

This combination of variables is considered strategic in international business and was realized in Ceará through a joint venture where the Port of Rotterdam (Netherlands) held a 30% stake in the Pecém Industrial and Port Complex. In this case, Rotterdam is well-positioned in the European market as a port complex that combines H_2V production and consumption with infrastructure for distribution to other European countries (pipelines to Belgium and Germany), import terminals, and electrolyzers[40].

From theory to practice, the logistical planning resulting from Pecém-Rotterdam would directly influence reducing hydrogen costs while meeting European market needs, providing a competitive advantage over other exporting ports. For reference, demand for H_2V from Rotterdam to Germany could reach 20 million tons per year by 2050, with 18 million tons coming from imports[41].

Thus, the considerations above reflect the promising international export market for Brazilian hydrogen aimed at Europe, specifically Germany.

Nuclear Cooperation between Germany and Brazil in the 20th Century

The dropping of two atomic bombs by the United States on Japan (Hiroshima and Nagasaki) at the end of World War II marked the beginning of the nuclear era, bringing with it the tragic effects of an atomic explosion. The world witnessed the dangers of using weapons of mass destruction, which became a symbol of power and a threat to human survival. Recognizing both the destructive potential and the civil applications of nuclear energy, U.S. President Dwight D. Eisenhower delivered a speech in December 1953 at the United Nations General Assembly, known as "Atoms for Peace."

The purpose of this speech was to characterize how the world should understand nuclear energy and its applications, specifically its peaceful use through the promotion of international cooperation in the field of nuclear energy. The concept behind the "Atoms for Peace" speech was the sharing of nuclear knowledge and technology with other nations, provided it was for non-military purposes and served as an opportunity for global benefit. The President encouraged nations to unite efforts to ensure that nuclear energy was used exclusively for peaceful purposes.

Not surprisingly, in the following decade, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) was signed, along with the establishment of the International Atomic Energy Agency (IAEA) in 1957, an

organization dedicated to promoting the peaceful use of nuclear energy and monitoring its application to ensure it is not diverted for explosive purposes. Subsequently, following the "Atoms for Peace" speech, bilateral cooperation between the Federal Republic of Germany and Brazil commenced in 1975 with the signing of the Agreement on Cooperation in the Field of Peaceful Uses of Nuclear Energy, which included the transfer of equipment and technology for all phases of the energy production cycle[42, 43].

The motivations that led Brazil to enter into this agreement stemmed from its current and future energy needs, particularly driven by the oil crisis of 1973 and the sudden decision by the U.S. government to suspend uranium enrichment supplies to Brazil in 1974 for use in the Angra-I reactor. As a result of this abrupt decision, the Brazilian government at that time redefined its nuclear policy to include the construction of eight nuclear reactors with German companies led by Kraftwerk Union-KWU, which would be responsible for developing various stages of nuclear energy production. Consequently, this nuclear agreement led to the establishment of an industry for manufacturing components and fuel for reactors over a period of 15 years with support from the National Nuclear Energy Commission (CNEN).

The Partnership between Germany and Brazil in the Context of Green Hydrogen

The strengthening of the bilateral relationship between Germany and Brazil occurred when both governments agreed to a Strategic Partnership in 2002, motivated, among other reasons, by economic and commercial interests. In 2008, the "Agreement on Cooperation in the Energy Sector with a Focus on Renewable Energies and Energy Efficiency" was signed. In 2009, the Brazil-Germany Energy Partnership was established as a high-level political forum aimed at supporting and diversifying sustainable energy production (renewables) and improving energy efficiency in both countries[22].

In the following decade, in 2015, the countries elevated the partnership through a mechanism known as High-Level Intergovernmental Consultations, an initiative that Germany maintains with only a few countries outside the EU (such as China, India, Israel, and Russia). Also in 2015, both countries committed to the total decarbonization of the global economy throughout the 21st century[29].

Germany's objective was to boost the hydrogen sector in countries with which it cooperates in the energy field[40]. This relationship involves direct participation from Brazil's Ministry of Mines and Energy, the Ministry of Foreign Affairs, and the Energy Research Company; from Germany, it includes the Federal Ministry for Economic Affairs and Climate Action and the Deutsche Gesellschaft für Internationale Zusammenarbeit. The political and legal framework was established by the Presidency of the Republic in 2012. It is noteworthy that Brazil is currently the only country with Germany as its exclusive partner in forming a value chain for H_2V[34].

It is also important to mention the Brazil-Germany Alliance for H_2V (AHK Green Hydrogen), created in 2020 by the Brazil-Germany Chambers of Commerce and Industry in Rio de Janeiro and São Paulo. The objective of this partnership is to promote and prospect business opportunities between Brazilian and German companies and institutions within the context of energy transition. This alliance believes that consortia would be formed for industrial projects (production, export, and import of H_2V) leading to the emergence of a new sustainable market. It adds that importing countries of H_2V would invest in producing countries due to the need to develop production and export infrastructure through financing in those countries. Another significant development was the update of Germany's National Hydrogen Strategy (Nationale Wasserstoffstrategie/NWS), when the government allocated an economic stimulus package amounting to €2 billion for developing an import structure and expanding the international H2V market[35].

With the NWS, Germany aims to double its production capacity from 5 to 10 GW by 2030 and build a network of 1,800 km of hydrogen pipelines by 2028. The NWS aims to make hydrogen competitive as an alternative energy source; foster markets and partnerships; and promote international cooperation. Following the launch of the NWS, Brazil and Germany furthered their collaboration by establishing a "Joint Declaration of Intent on the Partnership for an Ecological and Socially Just Transformation," which includes topics such as energy transition and decarbonization of economies.

Press Release No. 563 from Brazil's Ministry of Foreign Affairs (MRE) (2023) states that the joint declaration envisions reducing impacts from climate change-related events; creating green markets; and promoting efficiency in using low-carbon hydrogen[44]. Analyzing the objectives of both the NWS and the Joint Declaration reveals their similarities, indicating a convergence of purposes between the two countries (a "win-win" relationship): Brazil as a producer and exporter, and Germany as an importer of H_2V within this economic-energy relationship. Notably, in March 2024, Germany formalized a donation of up to €25 million for decarbonization projects in Brazilian industries with high carbon emissions, such as steelmaking and cement production[45].

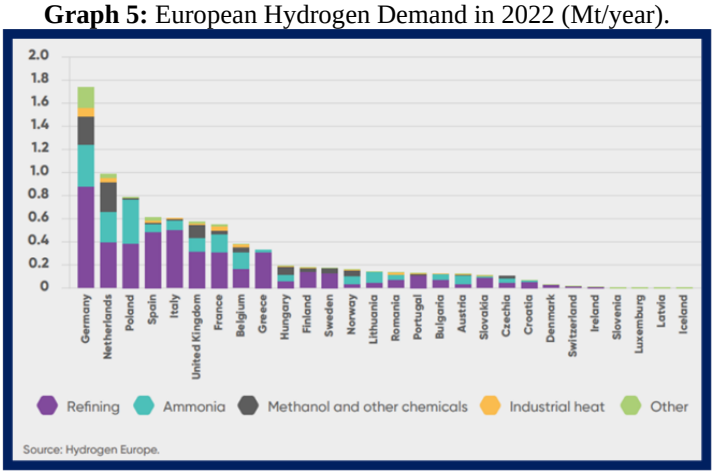
Thus, the partnership between Brazil and Germany takes on a strategic aspect, becoming a decisive factor for the energy transition, particularly through the production of green hydrogen (H_2V)[46]. To strengthen the ties between Brazil and Germany, GIZ is investing in the development of production projects in Brazil through a technical cooperation initiative called the DKTI-Brazil-Germany Technology Partnership for Energy Storage.

Another German institution of significant international relevance that has strengthened energy ties with Brazil is the Fraunhofer Institute, which has initiated new projects in partnership with Brazilian companies and organizations upon observing a substantial national market for the introduction of technological solutions and research activities. In the field of hydrogen, the Fraunhofer Institute has accumulated extensive expertise in research and development (R&D) and seeks to actively collaborate with Brazil for a sustainable energy transition through technologies that enhance the competitiveness of hydrogen as a renewable source[30].

Finally, it is worth mentioning the Brazil-Germany Alliance for H_2V, established in 2020 by the Brazil-Germany Chambers of Commerce and Industry in Rio de Janeiro and São Paulo. This alliance focuses on issues related to energy, technology, innovation, sustainability, and energy transition. With support from GIZ and the Ministry of Mines and Energy (MME), the alliance aims to promote partnerships and business opportunities between Brazilian and German companies and institutions, recognizing that renewable energies in Brazil offer some of the most competitive generation costs in the world.

Examining hydrogen demands in Europe (Graph 5), it is evident that Germany and the Netherlands were the largest markets in 2022[32], allowing for the conclusion of Brazil's strategic vision to strengthen economic ties with these two largest European hydrogen-consuming countries.

Graph 5: European Hydrogen Demand in 2022 (Mt/year).



Source: Port of Rotterdam[32]

Graph 5 illustrates the total volume consumed by country, highlighting that key sectors such as industry (including refineries and chemicals) and transportation traditionally lead the demand. It is important to emphasize the emerging role of green hydrogen as a sustainable alternative, albeit dependent on specific local energy policies.

IV. Conclusion

The process of transitioning from fossil fuels to renewable energy, currently underway, is irreversible and necessary to demonstrate the international community's commitment to mitigating the effects of global warming. This transition requires cross-border unity, a global synergy of efforts, and interdependence among various countries.

In the political, diplomatic, economic, and energy fields, many countries are developing the production chain for what is considered the fuel of the future: green hydrogen, particularly in response to extreme climatic events.

Thus, this article aimed to present the strategic relations between Germany and Brazil, with an emphasis on bilateral cooperation in the production of this energy vector. As a result of this energy diplomacy, it highlights how both states could mutually benefit in the 21st century from the process of decarbonizing the global economy.

The research achieved its objectives by providing a broad spectrum related to the imperative need to maintain the ongoing energy transition due to increasingly frequent and intense climate changes. It also demonstrated the high degree of energy integration between Brazil and Germany concerning the production and commercialization of green hydrogen, regarded as a solution to global warming.

Brazil stands to gain as a producer and exporter due to its abundance of renewable energies, particularly solar and wind resources, its favorable geographical position near Europe, and ports (hubs) that would facilitate commercialization in the European market—all of which would have a direct and positive impact on national exports. Germany would benefit by importing H_2V from Brazil to meet its domestic market needs at more advantageous prices and costs compared to other producing countries, thereby directly improving its energy independence from fossil fuels.

The qualitative approach through literature review was essential for understanding the complex political, diplomatic, climatic, and energy contexts, allowing for an in-depth discussion of the implications of maintaining economic decarbonization based on renewable energy use, with green hydrogen being a priority in European countries.

The research revealed that in this race, partnerships and international cooperation are indispensable for ensuring various initiatives among countries. However, it also became evident that investments in research and development of new disruptive technologies would be essential in this process. In this regard, the article demonstrated that Brazil and Germany, longstanding strategic partners in the nuclear field, are once again aligned in the 21st century to contribute to global energy transition.

For future research, it is recommended to monitor the effectiveness of the Brazil-Germany energy partnership, whether at the federal agency level or among public and private institutions, assessing the results of investments made and advancements in technologies necessary for the green hydrogen value chain. Additionally, it would be crucial to monitor how much hydrogen Brazil is exporting to the German domestic market during the production phase.

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