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THE EVOLUTION OF INTERMITTENT RENEWABLE ENERGIES IN BRAZIL

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ABSTRACT
The transition from the use of non-renewable sources to renewable sources is a worldwide reality. In this regard, Brazil is one of the few countries that use more renewable sources in its electricity matrix. The objective of this work is to contextualize and discuss some aspects related to the energy sector in Brazil. The methodology adopted is based on literature review information obtained from scientific articles, national and international documents of extreme relevance for the analysis and discussion of the theme, academic works and electronic pages directly or indirectly related to the energy sector. This theoretical essay encompasses introduction, theoretical foundation and conclusion. The study on the subject showed uncertainties in the face of the country's preparation for seasonal periods and the future.

Keywords: Renewable energies. Energy sources. Intermittent sources. Electric matrix. Energy matrix.

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INTRODUCTION

The end of the First Industrial Revolution (end of the nineteenth century) was the starting point for the production of electricity in Brazil. The first technological advances contributed to the transition of animal and human labor to the use of steam engines, gradually advancing to other industrial segments, such as chemistry, metallurgy and the textile industry. With this, the search for other sources of energy also began, seeking the expansion of the electric grids and boosting the economy in the country, already at the beginning of the Second Industrial Revolution (twentieth century) (PIOVANI; TRIGOSO, 2023, pg. 133; SAES, 2012).

Many changes occurred in this transition. Although the development of industry, engineering and technology were useful and necessary, at that time there were no concerns about future environmental impacts. With the increase in energy demand, fossil fuels, such as coal, oil, and their derivatives, which are the main agents causing climate change on the planet, have been exacerbated (*INTERNATIONAL RENEWABLE ENERGY AGENCY* (IRENA), 2023, pg. 30; PIOVANI; TRIGOSO, 2023, pg. 133).

The high concentration of greenhouse gases (GHG) emitted into the atmosphere is responsible for severe climate change, which includes extreme weather events such as hurricanes, longer periods of drought, *tsunamis*, increased global temperature, depletion of the ozone layer, among others, causing damage to the environment, society, and the world economy (IRENA, 2023, pg. 30; *UNITED NATIONS ENVIRONMENT PROGRAMME* (UNEP), 2022). This damage is observed with greater intensity over the years.

Since the 70s, scientists have been discussing the environmental damage caused by the use of fossil fuels on the planet. As a result, global government agreements were initiated, in search of other alternative methods of energy sources, aiming at global environmental preservation. It was a time when researchers began discussions on "Energy, Development, and Sustainability", reiterating the need for social, environmental, and economic awareness policies, based on the premise that fossil fuels are finite and that responsible use is essential, thinking about future generations (UNITED NATIONS BRAZIL, 2022).

Important international institutions have initiated campaigns and government agreements in search of strategies to reduce the consumption of fossil fuels around the world. With the "Paris Agreement", signed in 2015, countries seek alternatives to reduce the consumption of fossil fuels in the global energy and electricity matrix, increasing the

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use of renewable sources, as an attempt to keep the increase in the global average temperature below 2 °C, above pre-industrial levels, reaching 1.5 °C by the year 2050 (IRENA, 2023, p. 15).

Thanks to government agreements, it is expected that the world will consume less fossil fuels each year. Technologies targeting these fuels are losing market share to clean energy technologies around the world, thanks to nations' commitment to complying with the agreements. According to estimates, coal consumption is expected to fall by 60% by the year 2050 (*INTERNATIONAL ENERGY AGENCY* (IEA), 2023a, p. 26).

Brazil has also signed government agreements and has gradually replaced the use of fossil fuels with renewable sources over the years. Currently, Brazil is one of the countries that most use renewable sources in its electricity matrix, however, despite this differential, there are concerns about the medium and long-term electricity supply in the country, due to climate change that has affected the entire planet. Brazil is considered one of the richest countries in water and energy resources and even though water is the main and primary source for obtaining energy, periods of scarce rainfall have been a scenario of national concern, since hydroelectric plants are the predominant sources in the Brazilian electricity matrix (EPE, 2024; GOLDEMBERG; MOREIRA, 2005, p. 217, 226).

Despite the uncertainties in the face of periods of scarce rainfall, to meet the goals established by the "Paris Agreement", the Federal Government will bet on investments in small hydroelectric plants (or Small Hydroelectric Power Plants (SHPs) and Hydroelectric Generating Plants (HGCs)) in regions that have not yet been used, starting in 2026 (BRASIL, 2021, pg. 52). The National Energy Plan (PNE 2050), 2020, pg. 77) validated a hydroelectric potential of 176 GW, of which 108 GW would be in operation and construction by 2019 and also validated 68 GW of inventoried hydroelectric potential, distributed throughout Brazil, which includes hydroelectric plants (HPP) and hydroelectric projects smaller than 30 MW, identified and approved by the National Electric Energy Agency (ANEEL).

In the literature, Moretto, *et al.* (2012, p. 142), also state that there is a great hydroelectric potential available in the Brazilian territory, but unexplored by environmental restrictions. However, there have been many discussions and controversies regarding future hydroelectric projects in the country since the mid-2000s. For example, Bermann, (2007, pg. 139), mentions that hydroelectric plants are viable only in periods of high rainfall, when it is possible to obtain a greater amount of energy from the reservoirs. Goldemberg

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and Lucon (2007, pg. 19) mention that even with the abundance of renewable resources in the national energy matrix, the country wastes, in a way, greater growth in the sector, due to the lack of public policies and government issues in the energy sector. Nogueira (2007, pg. 103) emphasizes the situation, questioning the superficial policies adopted in the country, causing waste of raw materials in the energy sector and Vainer (2007, pg. 132) emphasizes that energy, the use and management of water resources together with the appropriation of territory and environmental resources are relevant and decisive in any national strategy or project in the country, due to the vast territory and extraction possibilities. As seen, these issues have been discussed since 2000 and have not yet been fully resolved.

International government agencies such as IRENA also bet on and encourage the construction of new HPPs across the planet (IRENA, pg. 68, 69, 2023).

In this context, there is a need to discuss whether it is feasible to invest more in new HPP projects and the current importance for more investments in other primary energy sources, taking advantage of the installation space of existing HPPs. With the worldwide advance of applied research for other renewable sources, such as solar energy, wind, green hydrogen (H2V) and ocean energy, the country wastes new investments and opportunities for expansion and autonomy, as already stated by Goldemberg and Moreira (p. 217, 2005).

Thus, the objective of this work is to contextualize and discuss some aspects related to the energy sector in Brazil. This work highlights the need to discuss the topic and the importance of establishing concrete goals for the advancement of new technologies, which implies joint actions by researchers, investments and federal and state responsibilities to achieve zero emissions in the country.

The methodology adopted in this research (which will be presented below) is based on literature review information obtained from scientific articles, national and international documents of extreme relevance for analysis and discussion of the theme, academic works and also electronic pages directly or indirectly related to the energy sector.

This theoretical essay consists of an introduction, rationale, and conclusion. The motivation is due to the need for a more current publication on the theme "energy" for this renowned journal, in addition to contributing with a more critical presentation of this theme to students, researchers and laypeople in all areas of knowledge.

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METHODOLOGY

The methodology adopted to achieve the proposed objective followed the following steps:

a) Bibliographic research: This stage was carried out to obtain data and information related to the theme, in books, scientific articles, theses, dissertations, documents and national and international technical reports, maps, various websites and documents directly or indirectly linked to the theme of Energy.

b) Theoretical framework: Articles and documents by seminal authors that address the theme were sought. In this case, older articles and reports were chosen to elaborate the theoretical basis. To compare the evolution of the national electricity matrix, the most recent (latest publications) and some older (2005 and 2015) reports from the Energy Research Company (EPE) were adopted[4]. To confront the information and evaluate the evolution of the electricity matrix over the years, preference was given to recent publications (published 5 years ago), since the energy sector is constantly expanding and has evolved over 20 years.

c) Selection of sectoral reports: Reports developed by government agencies and competent service providers that address prospects for expansion of the energy sector, considering the various energy resources available, were selected. EPE, together with the Ministry of Mines and Energy (MME), has actively participated in the major discussions regarding the Brazilian energy sector. The National Energy Balance (BEN) prepared by EPE and MME is extremely relevant, as it is an annual disclosure report on the supply and consumption of energy in Brazil, considering the activities of extraction of primary energy resources, conversion into secondary forms, import and export, distribution, and the final use of energy (EPE, 2023). EPE also works with other regulatory agencies, such as ANEEL, the National Water Agency (ANA), the National Electric System Operator (ONS) and the Electric Energy Trading Chamber (CCEE) (EPE, 2024).

The Ten-Year Energy Plan (2030) and (2034) are national informative documents, which show perspectives for future expansion of the energy sector by the Federal Government, in the long term (in the ten-year horizon) (EPE, 2024), so they are relevant for this study.

[4]The EPE was established under the terms of Law No. 10,847, of March 15, 2004 and Decree No. 5,184, of August 16, 2004.

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International reports were also adopted because they are interconnected with government agreements related to the Paris Agreement that are used worldwide for studies. IRENA, a leading global intergovernmental agency for energy transformation, supporting countries in the energy transition and providing state-of-the-art data and analysis on technology, innovation, policy, finance and investment, is founded by the United Nations (UN) (IRENA, 2011-2022). The IEA is associated with the Organization for *Economic Co-operation and Development* (OECD), which works with governments and industries to shape a secure and sustainable global energy future (IEA, 2023).

d) Theoretical essay: The essay conception adopted is described by Michel (2015):[5] "The academic essay defends an original idea or vision of something, and it does not need to be original in its conception, and may present a new bias, a new approach, a new characteristic, quality or problem of the object of interest".

The purpose of this work is to elucidate the reader on the subject, making him evaluate the theme and obtain his conclusions, from the reflections and final considerations listed in this work.

e) Division of Labor: This work has four sections, the first section being the introduction; the second section will address the evolution of the Brazilian electrical system; the third section discusses future investments in alternative renewable sources in Brazil and the fourth and final section will present the final considerations.

EVOLUTION OF THE BRAZILIAN ELECTRICAL SYSTEM

The Brazilian electricity matrix is a set of energy sources that are used to generate electricity. In 2023, the sum represented, on average, 89.2% of the use of renewable sources in Brazil. It is observed that renewable energies are predominant in the Brazilian electricity matrix (EPE, 2024, pg. 12).

Hydroelectric plants are the predominant sources in the generation of electricity, however, their use has been reduced annually, thanks to the addition of other renewable sources such as wind energy, biomass and solar energy. Figure 1 shows the Brazilian electricity matrix for 2023.

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[5] SOARES, S. V., PICOLLI, I. R. A.; CASAGRANDE, J. L. Bibliographic research, bibliometric research, review article and theoretical essay in administration and accounting. **Administration**: teaching and research, 19(2), p. 308-339, 2018.

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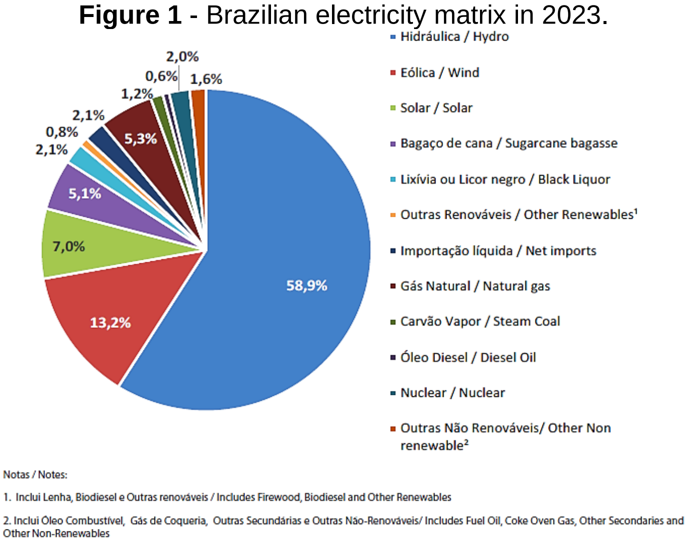
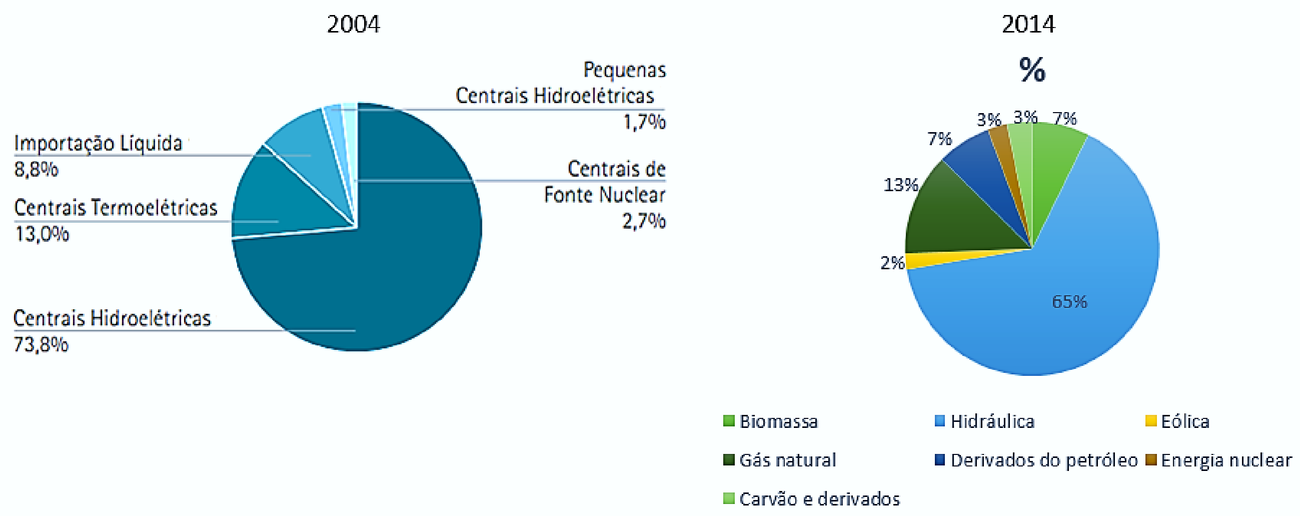
Figure 1 - Brazilian electricity matrix in 2023.



Source: EPE, 2024.

The Brazilian electricity matrix has been changing over the years, so that the use of renewable energy sources is intensified in the country. This is observed when comparing the sources used in the Brazilian electricity matrix in the years 2004 and 2014, seen in Figure 2 (EPE, 2005; 2015).

Figure 2 - Evolution of the Brazilian electricity matrix in the years 2004 and 2014.



Source: EPE, 2005; 2015 (adapted).

Figures 1 and 2 show that in an average period of 20 years, water sources still prevail, but have been decreasing. It is observed that in 2004 thermal energy was the second most used source, representing 13%. Brazil was dependent on exports to meet the country's electricity demand (EPE, 2005). Comparing the years 2004 and 2014, the presence of biomass and wind energy and a decrease in the use of non-renewable sources in 2014 can be observed.

Comparing the years 2023 (Figure 1) and 2014 (Figure 2), the reduction of fossil sources in the electricity matrix is observed. In 9 years, wind sources grew by an average of 11%. Biomass growth is also observed.

In the energy matrix, there were also changes. In 2020, about 48.4% of national primary energy comes from renewable resources, which contrasts significantly with the global average of 14.1% and the average of 11.5% compared to OECD countries (EPE, 2023a, pg. 12). Since 2004, Brazil has already occupied a prominent position in the use of renewable energies, when compared to the global average, seen in Table 1. In 2023, Brazil reached 49.1%. In this regard, Brazil presents a very favorable condition about other countries.

Table 1 – Evolution of the use of renewable sources in Brazil and the world.

Country/year	2020	2012	2010	2004
Brazil	48,4%	41,9%	44,7%	43,5%
World	14,1%	13,2%	13,2%	14%
OECD	11,5%	8,6%	8%	6%

Source: EPE (2024, 2023, 2022, 2015, 2012, 2004) (adapted).

Even with the evolution of the Brazilian electricity system over the years, Brazil has great potential to invest in other renewable sources, however, due to the lack of investments and legislation issues, there are delays in the processes, preventing short-term advances in the sector. Goldemberg and Moreira (pg. 217, 2005) already discussed these issues, alerting the need for more initial investments in energy policies to favor the growth of new markets and investments, opening up new opportunities, working conditions and specialized labor, as well as investments in technologies for the national production of parts and equipment, resulting in greater visibility and financial independence for the country.

THE ISSUE OF HYDROELECTRIC PLANTS IN THE BRAZILIAN ELECTRIC SYSTEM

From the twentieth century to the present, Brazil has undergone several transformations in the electricity sector. In addition to climate change issues, companies have adapted to new changes in habits, arising from the pandemic period (COVID-2019),

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which extended until the beginning of 2022. These changes promoted greater consumption of electricity in homes and this trend became worldwide.

The changes impacted a concern, discussed by researchers, regarding the need for plans and strategies in the electricity sector to meet the country's energy demand in the medium and long term (PIOVANI; TRIGOSO, 2023, pg. 135).

Hydroelectric plants, as already mentioned, are the main sources of electricity in Brazil, also given the existing geographical characteristics (EPE, 2021, pg. 15). The strong base of hydroelectric power makes the Brazilian electricity system vulnerable to climate variability, especially in seasonal periods that promote intense drought. This problem began in 2001, when there was a period of drought associated with a natural event, known as "La Niña", which seriously affected the hydroelectric system, causing "blackouts" in some regions of the national territory (PIMENTA; ASSIREU, 2015, pg. 757).

Since 2012, Brazil has been experiencing severe droughts (mainly in the Southeast, Midwest and Northeast), making it necessary to use thermoelectric plants to meet the country's demand. Thermoelectric plants are only activated in extreme events, however, in 2021, even with the increase in wind and solar sources in the electricity matrix, generation was insufficient, requiring its activation, which represented 19.6% in the electricity matrix. This trend of using thermoelectric plants has continued in recent years, which implies an increase in the use of fossil fuels in the Brazilian electricity matrix (DANTAS, *et al.* 2017, pg. 998; PEPPER; ASSIREU, 2015, pg. 757).

With the end of the drought, in 2022 the use of thermal sources reduced by 8% (about 5,373 MW), being the lowest rate recorded in the last 10 years (CÂMARA DE COMERCIALIZAÇÃO DE ENERGIA ELÉTRICA (CCEE), 2023, pg. 22).

The use of thermoelectric plants is unfavorable, as the extra cost is passed on to the tariff flag, increasing the electricity bills of residential, commercial and industrial consumers. Economic factors related to variations in the dollar, IGP-M (General Price Index – Market) and the increase in costs due to the low level of the reservoirs, are also passed on to the consumer (ANEEL, 2025; CÂMARA DE NOTÍCIAS AGENCY, 2021).

In Brazil there are 10 reservoirs; 91 run-of-the-river plants; 61 plants with reservoirs and 1 pumping plant (ANA, 2025). According to Figure 3, it is observed that in the years 2020 and 2021, the reservoirs operated with an average capacity of less than 50%. From 2022 to 2024, the reservoirs operated at less than 60% in the middle of summer.

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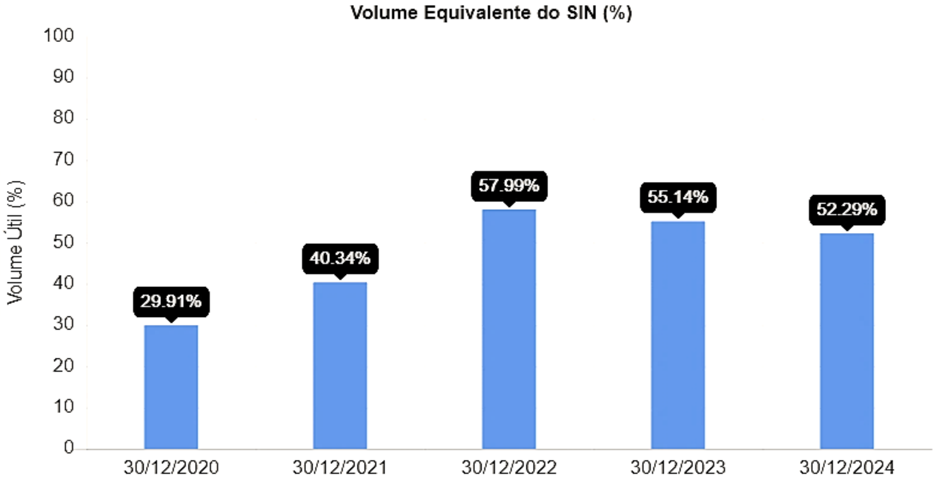
Figure 3 - Equivalent volume recorded in national hydroelectric plants by the National Interconnected System (SIN).



Source: ANA, 2025.

Hydroelectric plants are essential to maintain the high share of renewable sources in a country, in addition to contributing to low GHG emissions in the long term (IRENA, 2023, pg. 68; 69; BRAZIL, 2020, pg. 77). Due to the abundance of the resource in the country, the Federal Government is betting on large investments in this sector, however, the issue of hydroelectric plants has been discussed and is not well regarded, due to the environmental and social impacts caused by its implementation. In the case of hydroelectric sources, it can be said that they are viable sources due to the reduction of GHGs, however, they imply the use of large flooded areas and the infrastructure causes severe environmental and social damage.

ANEEL identified possible areas of hydroelectric use in practically all hydrographic regions of Brazil, however, most of the appropriate locations are located in the hydrographic regions of Amazonas and Tocantins-Araguaia (BRASIL, 2020, pg. 77), according to Figure 4.

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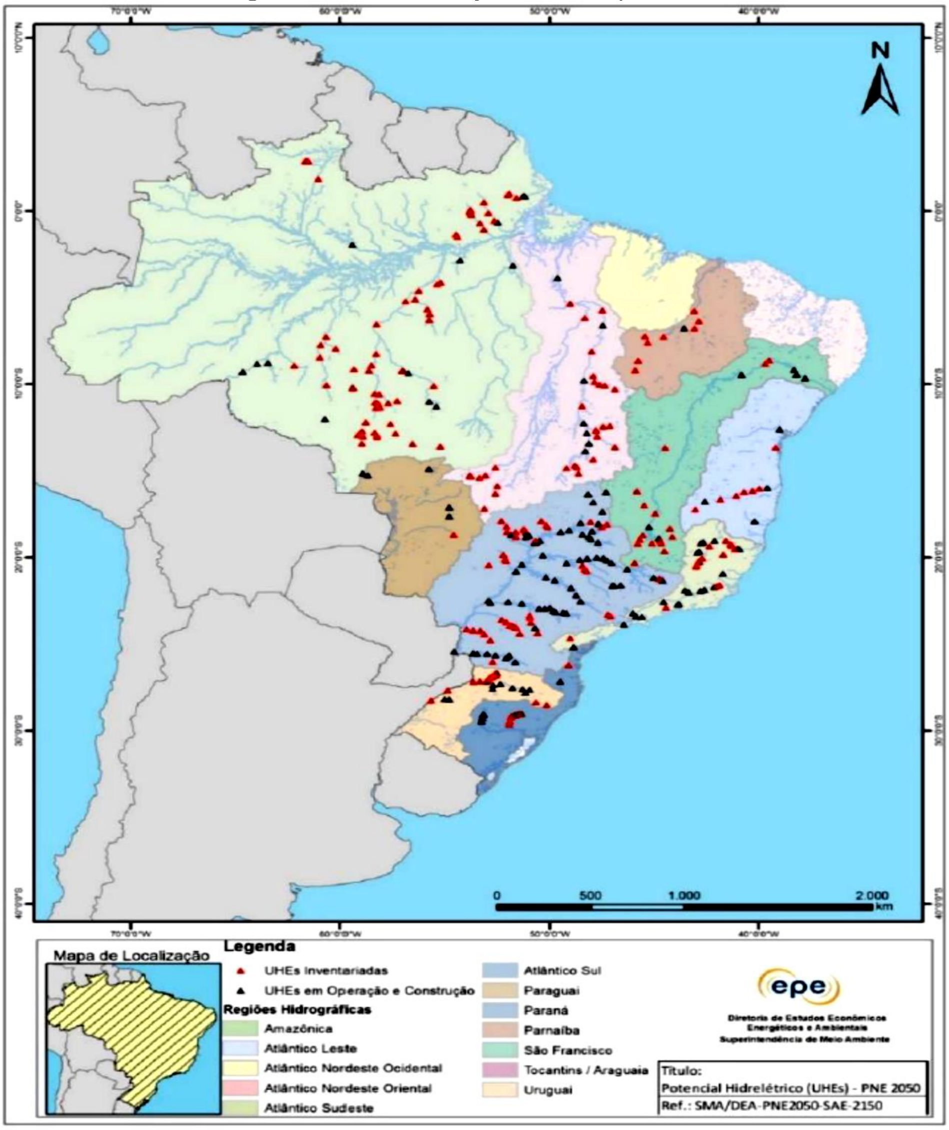
Figure 4 – National hydroelectric potential.



Source: BRAZIL, 2020.

Undoubtedly, the Amazon Basin, which is located mostly in the North region, has the greatest hydroelectric potential in Brazil, but has the greatest restrictions from an environmental and social point of view, where more than 44% of the potential presents direct interference with indigenous lands and future disturbances to local biodiversity (NADALETI; SAINTS; LOURENÇO, 2020, p. 1377; BERMANN, 2007, pg. 140). Thus, the environmental impacts caused by hydroelectric plants need to be studied in the medium and long term (MORETTO *et al*., 2012 pg. 142).

For Bermann (2007, pg. 140, 141) relevant investments are found in the basins of the Paraná and Uruguay rivers. It also emphasizes the need to evaluate these investments, considering other essential activities for the population such as fishing; irrigation; tourism and biodiversity.

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For Pereira, *et al.* (2017, pg. 12), investments in hydroelectric plants are also considered unfavorable, due to climate change accompanied by extreme events, which end up reducing reservoir levels, resulting in a drop in electricity generation capacity, also mentioned by Bermann (pg. 139, 2007), as they are intermittent sources, that is, they are dependent on the flow of rivers and the availability of water to generate enough electricity for supply.

On this issue of new hydropower projects, IRENA only supports projects that follow the *Hydropower Sustainability Standard*[6] that are being developed by China. It is a global certification scheme that details sustainability expectations for hydropower projects around the world (IRENA, 2023, pg. 68). Brazil is far from complying with the rules.

In view of the above, it is evident the need to review the issue of electricity supply in the country, thinking of other alternative sources of energy to complement the hydroelectric system, especially in periods of scarce rainfall, which has affected Brazil.

FUTURE INVESTMENTS IN ALTERNATIVE RENEWABLE SOURCES

In order to achieve the goals established by the Paris Agreement (2015), the world is looking for other renewable sources. Looking at the long term, a 77% increase in the use of renewable sources in the global energy matrix is needed to reach the goal of 1.5°C by 2050. To achieve the established goals, IRENA (2023, pg. 33) proposed six universal indicators, seen in Table 1:

Table 1 - Indicators listed by IRENA.

• Use renewable energies for electricity generation in both the electricity and energy matrix; • Consider the share of renewable energy in final energy consumption and the amount of modern bioenergy used; • To make improvements in the energy distribution network; • Invest in the infrastructure of the network distribution and end-use sectors. • Encourage policies for the production and supply of green hydrogen and derived fuels. • Capture and remove carbon dioxide.

Source: IRENA, 2023.

The big bets are focused on increasing biomass and the use of hydrogen gas (H2). The goal is for 94% of the H2 gas produced to be from renewable sources (IRENA, 2023, pg. 19). The use of H2 gas is related to the replacement of gasoline, encouraging electric

[6]Details of the *Hydropower Sustainability Standard* can be found at: https://www.hydropower.org/sustainability-standard.

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vehicles in the world market, despite the current cost being unfavorable worldwide (OLIVEIRA, R. C., 2022, pg. 19).

To achieve this challenging goal, it is believed that half of the reductions in these emissions will come from technologies that are currently in the demonstration phase or with a final prototype at scale for testing. Offshore technologies and technologies that use the environment, where rivers, lakes, courses or water mirrors are found, for example, are well regarded and are expanding across the planet.

Wind energy and ocean energy are technologies developed in the *offshore* environment; floating solar platforms are installed in the waters of hydroelectric plants, lakes and water mirrors. Ocean energies, which convert the energy of the oceans into electrical energy, are also at an advanced stage of testing on the planet. Many are already being evaluated on a full-scale in Europe, North America, the Asian region, and Oceania (*INTERNATIONAL ENERGY AGENCY-OCEAN ENERGY SYSTEMS* (IEA-OES), 2023, pg. 2).

And in Brazil? What are the proposals for these alternative sources? Floating solar systems (FPV), offshore wind energy, ocean energies and the production of green hydrogen (H2V) will be mentioned.

FLOATING PHOTOVOLTAIC SYSTEMS

The floating *photovoltaic system* (FPV) is one of the emerging technologies, seen as a potential source of energy for the coming years. Large tracts of land occupied by traditional solar panels to generate significant amounts of energy can be replaced by the use of the water surface for the installation of large photovoltaic plants (STIUBIENER *et al.* 2020, p. 765).

For Lopes, *et al.* (2022, pg. 1024) and Stiubiener *et al.* (2020, p. 765), Brazil has a promising potential for FPV installation, due to the variety and quantity of water bodies available in its territory. According to Lopes, *et al.* (2022, pg. 1024) ANA cataloged about 241 thousand water bodies in the country. In Brazil, FPVs are undergoing experimental tests and four plants have recently been installed, three in the State of São Paulo and one in the Fernando de Noronha Archipelago, as shown in Table 2. The 2019, 2016 and 2014 projects were developed to increase capacity, however, they were not adapted until 2023.

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Table 2 – Experimental Floating Photovoltaic Plants in Brazil.

Year	State	Plant	Power (start-end)	Source
2024	São Paulo	Billings Dam	Up to 5 MWp	EMAE, 2023
2023	Fernando de Noronha Archipelago (PE)	Xaréu Dam	630 kWp	COMPESA, 2022
2023	São Paulo	Mining pit, Roseira/SP	1 MWp	CONFEA, 2024
2023	São Paulo	Floating solar plant, Campinas/SP	1 MWp	SUNERGY 2024
2019	Bahia	Sobradinho Hydroelectric Power Plant	1 MWp	CHESF, 2019
2016	Amazon	Hydroelectric Power Plant of Balbina	1 MWp-5 MWp	BRAZIL, MME, 2017
2014	São Paulo	Rosana Plant	50 kWp-0.5 MWp	CESP, 2020

Source: Author, 2024.

FPVs could also be deployed in the reservoir of hydroelectric dams to complement existing infrastructure and improve energy production, using existing transmission resources, providing greater flexibility in terms of dispatching energy to the grid (LOPES, *et al.* 2022, pg. 1024; STIUBIENER *et al.* 2020, p. 765).

The point is that Brazil still invests very little in this technology, despite having exceptional geophysical conditions for expansion (STIUBIENER *et al.* 2020, p. 765). Brazil is privileged by the high incidence rates of solar radiation due to its geographical location, which favors the existence of solar rays, practically all year round, with variations in the national territory, which allows the development of viable solar projects in different regions, including under the surface of waters (BRASIL, 2020, pg. 109; PEREIRA, *et al.* 2017, pg. 20, 21).

The PNE (2050) describes four emergency situations that are necessary for the advancement of solar energy by 2030, described in Table 2 (BRASIL, 2020, pg. 116):

Chart 2 – Actions for the implementation of FPVs in Brazil.

- Provide better planning and management tools for the operation of the electrical system;
- Provide improvements in socio-environmental studies for future facilities;
- Integrate studies of expansion of solar generation and planning of energy transmission systems;
- Implement a regulation regarding the recycling of photovoltaic system parts.

Source: BRAZIL, 2020.

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OFFSHORE WIND FARMS

Like solar energy, wind energy is also a resource considered abundant in Brazil, especially in the Northeast Region. The competitiveness of the market was also an important factor for its growth, favoring the reduction of prices. As a result, Brazil invested in studies of *onshore wind potential* and qualified training to operate in the country, aiming at its development (BRASIL, 2020, pg. 99).

According to the PNE (2050), in addition to the *onshore* wind potential already identified, Brazil also has a great offshore wind potential. Estimates show that without the expansion of hydroelectric plants, wind energy would be the leading renewable source in the country that would surpass hydroelectric sources by 2050 (BRASIL, 2020, pg. 99). However, like solar energy, wind energy faces some challenges that need to be solved by 2030. The challenges are: to improve the generation for operation of the electric system by ONS; offer improvements in socio-environmental studies for the implementation of new wind farms; integrate wind generation expansion with expansion planning for transmission; and evaluate the logistics used to facilitate the transport of wind equipment (BRASIL, 2020, pg. 108).

The predominant factor for installing this equipment is to have constant wind speeds, without major changes in speeds or directions. The characteristics of the winds in Brazil were important for new investments, as wind generators in Brazil reach a capacity factor of more than 50%, while the world average varies from 20% to 25%. In the initial mapping of the offshore wind potential available in Brazil, areas with winds greater than 7 m/s were identified, concentrated mainly in the Northeast and South regions (ABEEÓLICA, 2025; BRAZIL, 2020).

According to Table 3, there are 96 projects in the environmental licensing process opened by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) (BRASIL, 2024). It is observed that the greatest potential is available in Rio Grande do Sul (RS).

Table 3 – Offshore wind energy projects under environmental licensing in Brazil.

State	Projects	Power (MW)
Santa Catarina (SC)	1	5.700
Rio Grande do Sul (RS)	27	69.629
Rio de Janeiro (RJ)	14	38.661
Espírito Santo (ES)	6	11.230
Rio Grande do Norte (RN)	14	25.468
Piauí (PI)	6	13.014
Maranhão (MA)	3	6.168

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Ceará (CE)	25	64.351
Total	**96**	**234.220**

Source: BRAZIL, 2024 (adapted).

It is observed that the issue of offshore wind energy development is similar to solar energy in floating systems. Both need legislative evaluation and more investments in the sector, mainly related to the need to expand complementary power, as they are intermittent sources (BRASIL, 2021, pg. 51). That is why broader and more detailed studies on the subject are needed for possible long-term installations.

OCEAN ENERGIES

Generally speaking, ocean energy technologies refer to wave energy, tidal (tidal), tidal currents, ocean (or marine) currents, and ocean thermal energy conversion (*Ocean Thermal Energy Converter* (OTEC)). Tidal and ocean currents are associated with the horizontal movement of waters, coming from meteorological tides. Tidal energy is related to the gravitational forces of the Earth-Moon-Sun system (Lewis, (MOURA, *et al.*, 2018)*et al.* 2011). Currently, the European Union is a leader in this segment and aims to generate 1 GW of ocean energy by 2030 and 40 GW by 2050 (IEA, 2021, pg. 63, 64).

A differential of ocean energies is that they are predictable, that is, they are not intermittent sources. Existing tidal energy variations are often cited as "low" compared to other renewable energy sources and tidal periodicity allows accurate predictions through harmonic analysis or modeling techniques (LEWIS, *et al.* 2019).

In Brazil, practical studies regarding ocean energies began in 2013 at the Alberto Luiz Coimbra Institute, at the Federal University of Rio de Janeiro (COPPE/UFRJ), in partnership with *Seahorse Wave Energy*, where a preliminary study was carried out that estimated a national theoretical potential of 114 GW, considering only the tidal and wave energy resources along the entire Brazilian coast, as shown in Figure 5. In the North region alone, the theoretical potential available for tidal energy is 27 GW and in the Northeast, Southeast, and South regions, the theoretical potential for wave energy reaches around 87 GW (TOLMASQUIM, M. T. 2016, pg. 417).

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Figure 5 - Regional distribution of the energy potential of waves and tides in Brazil.

Source: TOLMASQUIM, M. T., 2016.

The initial big bet in Brazil was in the tidal energy segment, in the northern region of the country. Over time, studies in wave technology and OTEC began on the Brazilian coast. However, the issue of tidal energy development is mainly framed in environmental issues, as it is a grandiose investment, similar to HPPs, in addition to the possible environmental impacts in environmental protection areas.

Except for tidal energy, which is consolidated in Europe, the other sources are undergoing advanced tests, many on a full scale of operation.

The research group of the National Institute of Science and Technology in Ocean and River Energies (INEOF) and Shadman, *et al.* (2019, p.11) report that tidal and marine current energy is unfeasible in Brazil, due to the low speed of sea currents on the seabed, however, studies referring to the speed of currents on the Brazilian coast show the need for in-depth studies for the installation of low-speed tidal current equipment, where countries such as China, The Philippines and Indonesia are conducting full-scale tests. Many characteristics of the coastline of these countries resemble the characteristics of the Brazilian coastline, highlighting the need for research on the subject (PIOVANI, 2023).

GREEN HYDROGEN (H2V)

Hydrogen gas (H_2) is not found in nature in viable quantities for production, being, therefore, an energy vector, that is, an energy store. For its production, it is necessary to extract it from a primary source of energy, which contains H_2, because H2 gas is a secondary source of energy. (LINARDI, 2010)

Currently, the production of H2 gas in Brazil is centralized in the oil segment (refining and industry) and fertilizers (ammonia). It is worth mentioning that H2 gas obtained from petroleum and other fossil sources is not H2V, as they release CO2 and CO into the atmosphere (OLIVEIRA, R. C., 2022, pg. 6).

H2V can be obtained by the process of water electrolysis and by solar thermochemical systems (GUO, *et al.* 2010, pg. 4422)element. Therefore, offshore renewable energies and floating photovoltaic systems are promising technologies and the most suitable for the production of H2V, since they are technologies already interconnected to an electricity grid. Ocean energy is also evaluated for long-term H2V production.

Researchers propose that offshore wind resources and FPVs be used to complement Brazil's electricity system, based on the development of hybrid wind-hydroelectric or solar-hydroelectric projects, especially in remote locations (PIMENTA; ASSIREU, 2015, p. 765).

Investments in H2 are found in Resolution No. 6, of June 23, 2022, of the National Energy Policy Council (CNPE), which created the National Hydrogen Program (FUNDAÇÃO GETÚLIO VARGAS (FGV), 2023).

The climatic conditions in Brazil are favorable for generating electricity from H2V. The trend of reducing the costs of renewable energies (in particular, solar photovoltaic and wind), favors the interest in obtaining hydrogen by electrolysis of water, especially with investments in offshore wind energy around the world (AGÊNCIA SENADO, 2023a; OLIVEIRA, R. C. 2022, pg. 17).

Brazil is also betting on H2V, after offshore wind installations, which will probably occur after 2030, however, for implementation, including new investments, it is necessary to evaluate the technical and economic feasibility of the technologies and improve the technological, legal, regulatory, environmental, social and governmental aspects for future investments in the country (BRASIL, 2018a, pg. 163).

FINAL CONSIDERATIONS

The need to reduce GHGs in the atmosphere in compliance with the Paris Agreement was important for world nations to evaluate the use of renewable and non-renewable fuels in their respective energy matrices. Brazil is in an advantageous position, as it uses more renewable sources, thanks to hydroelectric plants that currently generate uncertainties for the future.

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The issue in Brazil is once again interconnected with technological development and investments in infrastructure, thinking only in the medium and long term. Despite the investments made in Brazil to meet the Paris Agreement, other countries, including emerging ones, have been carrying out research and investments for some time to implement alternative renewable sources, referring to floating solar energy, *offshore wind* energy, and ocean energy, while in Brazil preliminary studies are taking place, due to the lack of more investments in research and the lack of partnerships between educational institutions and companies. These partnerships are carried out in developed countries and this has leveraged investments and advances.

In the case of ocean energies, another segment widely studied and indicated as a "source of the future" by several international reports (including IRENA and IEA-OES) is the technology of energy use by speed of tidal currents, however, in Brazil, there are no records of these currents in any institutional body, which makes it difficult to carry out research. Also reported by researchers (including Piovani, 2023). It is necessary to map the speeds of tidal currents on the Brazilian coast, as was done for offshore wind energy.

With Law No. 15,097, sanctioned on January 10, 2025, which "provides for the use of Federal Government assets for the generation of electricity from offshore enterprises*",* opportunities are opened for Brazil in investments and research in the sector that includes ocean energy. The Law is a necessary advance for the country since offshore wind projects have been evaluated from *onshore wind projects*, as is the case of the study for the installation of offshore wind farms on the Brazilian coast.

Brazil has a long coastline, diversified in resources, however, due to the lack of incentives and partnerships, it ended up wasting opportunities to become a leading country in the use of renewable energy, since offshore wind energy has been researched since 1991, in Denmark, according to the Ministry of the Environment. In Brazil, the first study carried out was the "*Offshore Wind Roadmap Brazil*", published in 2020.

To produce H2V there are several storage and transport issues through pipelines and special tanks that will have higher costs and a logistics evaluation will be necessary for transport at sea and on land. This issue of storage has been discussed worldwide.

Specific laws and standards for certification are another unfavorable issue, due to bureaucracy and slow actions. As a result, Brazil is "behind" compared to other countries, because many of these investments made by development agencies are tests, while in developed countries and even in some emerging countries, there are prototypes tested on

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a real scale. Regulatory standards are therefore important, as they can speed up the process or constitute a strong impediment to it.

As a result, despite the favorable conditions already mentioned about other renewable sources, there are many uncertainties regarding the implementation of these projects by the year 2050. It is essential to offer and ensure economic viability for new investments in the country.

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