DOI: 10.46551/rc24482692202316

Revista Cerrados ISSN: 2448-2692

https://www.periodicos.unimontes.br/index.php/cerrados

The dynamics of renewable energies in the Brazilian energy matrix in the 21ST century

A dinâmica das energias renováveis na matriz energética brasileira no século XXI

La dinámica de las energías renovables en la matriz energética brasileña en el siglo XXI

Daniel Féo Castro de Araújo
Universidade de Brasília – UnB, Brasília (DF), Brasil
daniel.feo@gmail.com

Abstract

In the early 21st century, Brazil began adopting a series of energy policies aimed at analyzing and understanding the dynamics of its energy matrix. In this context, this article aims to analyze the dynamics of the Brazilian energy matrix based on the main energy policies adopted in the early 21st century. The research methodology begins with a bibliographic review on the topic, directed at understanding the studied dynamics, as well as the construction of a theoretical framework from directly and indirectly related works. The bibliographic survey was conducted through research in libraries, digital repositories, and scientific journals, referencing books, dissertations, theses, databases, and articles related to the topic. This investigation is important as it deals with energy-related issues that are related to climate concerns. We conclude that, based on existing data, although there are concerns and debates about the environment and climate change in Brazil, there has been little progress in terms of the percentage of renewable energy sources incorporated into the Brazilian energy matrix between 1990 and 2020. Examining the Brazilian energy panorama in 1990 and 2020, we can see that the share of renewable sources reached 49%, making it the highest percentage of renewable sources in the internal energy supply during this period of analysis, with 51% of non-renewable sources.

Keywords: Renewable energy. Energy matrix. Brazil.

Resumo

No início do século XXI, o Brasil passou a adotar uma série de políticas energéticas com o objetivo de analisar e compreender a dinâmica de sua matriz energética. Nesse contexto, o presente artigo tem como objetivo analisar a dinâmica da matriz energética brasileira a partir das principais políticas energéticas adotadas no início do século XXI. A metodologia de produção da pesquisa inicia-se com a revisão bibliográfica a respeito do tema,

direcionada ao entendimento da dinâmica estudada, bem como a construção de referencial teórico de obras diretamente e indiretamente relacionadas. O levantamento bibliográfico foi feito por meio de pesquisa em bibliotecas, repositórios digitais e revistas científicas com a referência de livros, dissertações, teses, banco de dados e artigos relacionados ao tema. Esta investigação é importante, uma vez que lida com assuntos relacionados à energia, que se relacionam com questões climáticas. Concluímos que, à luz dos dados existentes, ainda que existam preocupações e debates acerca do meio ambiente e mudanças climáticas no Brasil, nota-se que houve pouca evolução, em termos percentuais, na matriz energética brasileira entre 1990 e 2020, no que diz respeito à incorporação de fontes de energia renováveis. Examinando o panorama energético brasileiro em 1990 e 2020, podemos notar que o número de fontes renováveis atingiu 49%, sendo assim, o percentual mais elevado de oferta interna de energia com origem renovável neste período de análise, com 51% de participação de fontes não-renováveis.

Palavras-chave: Energias Renováveis. Matriz Energética. Brasil.

Resumen

A principios del siglo XXI, Brasil comenzó a adoptar una serie de políticas energéticas con el objetivo de analizar y comprender la dinámica de su matriz energética. En este contexto, este artículo tiene como objetivo analizar la dinámica de la matriz energética brasileña en función de las principales políticas energéticas adoptadas a principios del siglo XXI. La metodología de investigación comienza con una revisión bibliográfica sobre el tema, dirigida a comprender la dinámica estudiada, así como a la construcción de un marco teórico a partir de obras relacionadas directa e indirectamente. El levanta-miento bibliográfico se realizó a través de investigaciones en bibliotecas, repositorios digitales y revistas científicas, referenciando libros, disertaciones, tesis, bases de datos y artículos relacionados con el tema. Esta investigación es importante, ya que aborda cues-tiones relacionadas con la energía que están vinculadas a preocupaciones climáticas. Concluimos que, según los datos existentes, aunque existen preocupaciones y debates sobre el medio ambiente y el cambio climático en Brasil, ha habido poco avance en tér-minos de porcentaje de incorporación de fuentes de energía renovable en la matriz ener-gética brasileña entre 1990 y 2020. Al examinar el panorama energético brasileño en 1990 y 2020, podemos observar que el porcentaje de fuentes renovables alcanzó el 49%, lo que lo convierte en el porcentaje más alto de oferta interna de energía de origen reno-vable durante este período de análisis, con un 51% de participación de fuentes no reno-vables.

Palabras-clave: Energias renovables. Matriz energética. Brasil.

Introduction

After the retake of democracy in Brazil, in 1985, and with the end of the military dictatorship that started in 1964, the elected governments started to show concerns with socioenvironmental issues in the international context. That was very clear in the discussions about climate and human rights, which gained more highlight in the Brazilian political agenda. This fact resulted in active participation of Brazil in multilateral negotiations, which contributed to the strengthening of the country as global actor. That change reflected a growing concern with the development of productive

forces in the capitalist mode of production in Brazilian territory, the environment, and people well-being.

In the global context of Tio-92 Conference, held in Brazil, the country established energy strategies turned to expand the use of renewable sources. This event had significant relevance, because it draws the world's attention to the importance of sustainability. As of this milestone, Brazil started to direct investments in alternative energy sources, like biomass, solar and wind energy (TOMALSQUIN, 2016). This change of approach reflects Brazil's stronger commitment with energy transition and the search for cleaner and more sustainable sources, in line with the principles of environmental protection and mitigation of climate changes' impacts. Renewable energy sources have gained space in the Brazilian energy matrix, driving the matrix diversification and contributing to reduce its dependence on non renewable sources and their environmental consequences.

The implementation of legislations turned to encouraging the use of less pollutant vehicles and reduction of energy waste was an important step towards a more sustainable future for the planet. However, it was in the 1990s that solar and wind energy started to be explored, and only after 2015 a significant increase in their adoption occurred. That is due to technological innovations and investments in research and development of these alternative energy sources.

Brazil has stood out in the development of technologies to use renewable energies, like photovoltaic solar panels, wind turbines, and biofuels. This technological evolution has been a driving factor to greater incorporation of these renewable sources in the energy matrix, contributing to the diversification and reduction of dependence on non renewable sources, like petroleum. It is worth noting that the continuity of investment in research, innovation, and policies to encourage the use of renewable energy sources is fundamental to further expand the participation of these sources in the Brazilian energy matrix, promoting a more sustainable and resilient future to the country and to the planet as a whole.

In this context, the present article aims at analyzing the dynamics of the Brazilian energy matrix, considering the main energy policies adopted in the early 21st century. It also seeks to identify challenges and opportunities faced by the country in the

search for a more sustainable and diversified energy matrix, in order to contribute to the debate on Brazil's energy future and its insertion in the global context.

Based on the above, this paper seeks to analyze how the changes in the internationalization process of the energy transition and the energy policies adopted in Brazil at the beginning of the 21st century have influenced the transition to a more sustainable energy matrix. Aspects like diversification of energy sources, promotion of energy efficiency and mitigation of climate changes will be examined. The main challenges faced by the country in this process will also be identifies and possible solutions will be proposed to reach a more sustainable and resilient energy matrix.

To fulfill the objectives proposed, the following methodology was adopted: literature review on the theme, with focus on the understanding of the Brazilian energy matrix dynamics, and the construction of theoretical reference based on the works directly and indirectly related to the subject. The bibliographic survey was conducted in libraries, digital repositories and scientific journals, including books, dissertations, theses, data banks and articles related to the theme. In this search, authors like Sampaio (2022), Pereira (2019), Silva (2021) and Conte (2022) were consulted to clarify the elements that make up a critical analysis of the subject.

To understand the changes occurred, this paper discusses, in its first section, the main strategies to encourage the use of renewable energy sources (solar, wind, and biofuels), and the reformulation the electricity sector faced in the period studied. The following section brings the numbers related to the investments in renewable energies in Brazil during the mentioned period and their relation with the change in the country's energy matrix.

The results obtained with the analyses conducted may provide valuable contribution to the understanding of the changes occurred in the Brazilian energy matrix, enabling the formulation of more efficient energy policies, aligned with the current demands of sustainability and energy diversification. Such results may be used as base for informed decision making, based on evidences, aiming at the development of more appropriate strategies to the use of clean and renewable energy sources in Brazil. Thus, the conclusions obtained from these analyses can be used as subsidy to implement more effective and sustainable measures in the

energy sector, contributing to a more conscious and sustainable future in terms of use of energy resources.

Mapping of the Brazilian energy policy

As of the 1980s, the Brazilian energy sector faced a series of difficulties, including economic crisis and political instability. During this period, Brazil underwent economic crises, hyperinflation, high interest rates, and external indebtedness, which had negative impact in the energy sector, causing financial restrictions and lack of resources for investments in infrastructure and modernization. Moreover, the increase in energy demand was another challenge faced by the sector, since it grew significantly due to economic growth and industrial expansion, but the capacity of energy generation and distribution did not follow this increase, resulting in supply and rationing issues.

Another factor that contributed to the difficulties faced by the Brazilian energy sector in the 1980s was the lack of investments in infrastructure. The reduction of investments in the sector resulted in lack of modernization and expansion of systems of energy generation and distribution, affecting their capacity of generating and distributing energy efficiently and reliably. Besides, technological changes and international competitions also represented challenges. The global energy industry underwent significant changes, like the development of new energy sources, and increase in international competition in the offer of technologies and equipment to the energy sector, pushing the Brazilian energy sector to modernize and adapt to these changes, which not always occurred efficiently.

During the 1990s, Brazil approved Law Lei 8.631, of 1993, in order to strengthen the electricity sector of the country. Such law considered costs for the service supply, allowing power utilities to propose adjustments in electricity prices to provide more control over the sector costs, resulting in more efficiency and competitiveness in the market. The lay revoked the Account of Results to Offset (CRC) and the remuneration regime previously defined, however, power utilities were still obliged to fulfill their financial obligations. The law prohibited defaulting companies from receiving any type of fund of guarantee from the Union or entities linked to it, until the payments were duly made. This measure obliged power utilities to fulfill their

financial obligations with the government and keep their services up-to-date (BRASIL, 1993).

The Project for the Electric Sector Restructuring (RE-SEB) brought significant changes for the management of electricity in Brazil, as observed by Sampaio (2022). Law 8.631 of 1993, which marked the start of this modernization process, was intended to increase the electric sector efficiency and competitiveness, in addition to reducing costs to consumers. One of the measures implemented was the institution of distinct tariffs for electricity supply and distribution, to encourage energy saving, because the charge is based on the consumption profile of each customer. The law also established criteria to grant discounts, exemptions, and other advantages in tariffs, benefitting consumers.

Real Plan launch in 1994 had significant impact in Brazil, and was efficient to control inflation through currency depreciation and market opening. Though beneficial to the economy, this measure caused deterioration in Brazilian external accounts, leading to deficit in its trade balance, despite the primary surplus resulting from the increase in commodities price. Furthermore, the increase in the demand for imported products contributed to the deficit in current account. In this economic context, where friendly environment and climate policies were sought, the government launched several programs to Foster the use of new energy sources as response to international pressures and the need to diversify the Brazilian energy matrix (MAUAD; FERREIRA; TRINDADE, 2017).

The Program for Energy Development of States and Municipalities (PRODEEM) was created in 1994 to promote the use of renewable energy sources in Brazil. According to Pereira (2019), PRODEEM was pioneer in the use of photovoltaic and wind turbines systems to provide electricity to isolated communities that did not have access to the power grid. This initiative aimed at promoting self-sustainable, social and economic development of these regions by means of access to clean and renewable energy. Thus, PRODEEM was an important milestone in the insertion of renewable energies in the Brazilian energy matrix, and contributed to promote a more sustainable and inclusive energy model.

In 1995, only a year after the start of the Project for Development of Wind and Solar Energies (PRODEES), the Center of Electricity Research (Cepel) created the

Sérgio de Salvo Brito Reference Center for Solar and Wind Energy (Cresesb). Cresesb was created to support studies and projects involving renewable energies in Brazil, aiming at their insertion in the country's energy matrix. Its mission is to promote the use of clean and renewable energy sources, contributing to reduce pollutant gases emission in the atmosphere, generate jobs in technology and innovation and income for underserved populations (MAUAD, FERREIRA, TRINDADE, 2017).

In 1995, a series of adjustments in the energy sector was driven by Laws 8.987 and 9.074, according to Sampaio (2022). These laws brought significant changes in the structuring of companies. Law 8.987 established norms for concession of public services, including the right o review tariffs. Law 9.074, in turn, defined the privatization standard to be adopted, established rules for authorization and concession of the public service, created the figure of the independent electricity producer and allowed high level consumers to acquire energy from other power utilities and independent producers.

Since then, the Brazilian electricity sector underwent a broad modernization process, with entry of new companies and investments in infrastructure. These changes promoted greater opening of the energy market, enabling the participation of several agents, and encouraging competition. As result, there was more diversification in the Brazilian energy matrix, with incorporation of renewable sources, like solar and wind, and higher efficiency in the offer of electricity to consumers.

After the privatization of several state-owned energy companies, like Rio de Janeiro Electricity Company, some companies remain under state control, such as Furnas and Chesf, according to Sampaio (2022). These companies are considered strategic to the country, and so the privatization process faced resistance. However, it is expected that these companies will be gradually privatized in the coming years, following the market opening trend and the search for more efficiency and competitiveness in the energy sector.

In 1996, the National Electric Energy Agency (ANEEL) was created, and started operating in 1997. The main goal of this regulatory agency was to regulate and inspect all aspects related to electricity, from generation to transmission, distribution and commercialization. That included monitoring of electric companies to ensure that they were complying with the norms and the services rendered were compliant with the

standards established. ANEEL also had as mission to promote the improvement of the Brazilian electricity sector, seeking to increase its efficiency and reduce costs, always for the benefit of consumers and promotion of sustainable development of the energy sector in the country.

In the following years, there was a series of actions to restructure the laws. Law number 9.433, of 1997, created the National Water Resources Management System and the National Water Resources Policy, in order to establish a regulatory framework for the sustainable management of water resources in Brazil. With that, mechanisms were created to protect rivers and lakes and promote the rational use of water. In 1999, the Director of the National Waters and Electricity Department (DNAEE), regulatory agency of the granting authority, established, by means of DNAEE Ordinance nº 466 of 11/12/1997, the General Terms for Provision of Electricity, compliant with the Consumer Protection Code.

In this regard, law 9.648, of 1998, played a fundamental role in the modernization of the Brazilian electricity system for defining the National System Operator and the Wholesale Energy Market as regulatory bodies of the sector. The creation of these bodies was important to ensure efficiency and transparency in activities involving generation, transmission, distribution, and commercialization of electricity in the country. The law also contributed to establish clear and objective rules for the electricity market, promoting competition and attraction of investments to the sector. With that, it was possible to improve the quality and safety in the supply of electricity to Brazilian consumers.

During the decade, Eletrobras acknowledged the importance of incorporating in its process the socioenvironmental issue related to international concerns with the environment and climate changes. Cepel was consolidated as reference company in social responsibility and efficient use of water. As part of this commitment, in 1997, the Efficient Solar House was created to encourage research and disseminate the benefits of photovoltaic solar energy (ELETROBRAS, 2022). Since then, the Efficient Solar House has promoted several events and activities to disseminate the benefits of solar energy, becoming reference in research on the use of photovoltaic solar energy in the country.

In 1998, ELETROBRAS created the National Interconnected System (SIN) and the National System Operator (ONS) to ensure efficient and safe electricity distribution

to the whole country. SIN implementation enabled hydroelectric plants to operate jointly, making possible the transfer of large amounts of energy to regions with higher demand. That substantially reduced the chances of shortage and regional problems resulting from periods of drought, which formerly could directly impact on the production capacity of plants (ELETROBRAS, 2022).

In 2001, the blackout crisis became reality due to inadequacies resulting from the transformations implemented in the electric sector in previous years. This reality was verified by the Hydrothermal Power System Analysis Commission (2001) report that pointed out several problems in the sector's infrastructure. Therefore, Brazil suffered severe energy shortage that directly affected the economy and people's lives. To face this crisis, the government adopted emergency measures to increase energy offer, like rationing, hiring of thermoelectric projects, and creation of the Brazilian Electricity Trading Company. Moreover, the Emergency Capacity Charge was established to guarantee the financing of these programs. Despite the problems, the country managed to overcome the crisis over time, and today, the electric sector is one of the best structured worldwide.

The government decided to start the Wind Energy Emergency Plan in 2001, despite that, the project was never put into practice, and, in the following year, the Program for Incentive to Alternative Electricity Sources (PROINFA) was created, by means of Law 10.438. The program prepared the ground for renewable energy auctions (KRELL; SOUZA, 2020). According to Conte (2022), PROINFA was a great promoter of the use of renewable energy sources in Brazil; biomass plants, small hydros and wind plants are outstanding. The program contributed to consolidate the industry of wind turbines and their components in the country, due to the requirement of at least 60% of nationalization (CONTE, 2022). This policy ensured that Brazilian companies could compete with multinational companies in energy auctions.

PROINFA, in the beginning, faced some obstacles, because there were few manufacturers in Brazil to meet the nationalization policy established. Until 2008, there was only one wind turbine plant operating in the country, as observed by Conte (2022). Moreover, the author identified a series of complications to obtain financing, particularly for small entrepreneurs, due to guarantees required by banks and the bureaucracy inherent in PROINFA program. This scenario made increasingly difficult

for these entrepreneurs to obtain the capital required to invest in the growth of their companies.

After the 2001 Blackout, the Brazilian government implemented a series of measures to reform the electric sector institutional model in 2003. Provisional measures were established for trading of electricity and the Energy Planning Company (EPE) was created, which later became Energy Research Company. EPE's responsibility is the planning of the Brazilian electric sector, conducting studies and research to ensure the supply of quality electricity, accessible to all Brazilians.

In 2004, the provisional measures that implemented the New Institutional Model were transformed into laws, with numbers 10.847 and 10.848. Thus, a new paradigm of relation between the State and the society was established, based on transparency and social participation. The main objective was to provide more affordable tariffs, ensure reliability in electricity supply, establish a solid regulatory framework, and contribute to the development of social inclusion in the Brazilian electric sector, using the programs for universalization of the services.

Thanks to the reforms, the auctions became a fundamental part for energy purchase and sale agreements. These auctions occurred both for existing sources and new generation sources. With the auctions, companies could negotiate better prices and conditions, making the market more competitive. According to Fuga (2022), the auctions were used as instruments to promote the growth of renewable sources, particularly with Decree 6.048, of 2007, which determined specific auctions for alternative sources. That increased competitiveness and reduced the prices of alternative sources, increasing their participation in the market. The auctions also allowed the entry of new players in the energy market, generating more innovation and diversification.

The changes in the electric sector had positive impact on the increase of investments in renewable sources like solar and wind energies (SILVA JÚNIOR, *et al*., 2023). These sources offer a more efficient, safer and more environmentally sustainable electricity supply that has contributed to the growth in the renewable energy sector, which has gained more space in the market. Formerly considered too much expensive, renewable sources are now becoming more competitive in relation to fossil fuels, mainly in the last years. Solar energy cost, for example, is comparable the cost of energy generated from oil and natural gas. These costs tend to fall in the coming years,

as technologies become more efficient and advanced. For this reason, renewable energy sources will play an increasingly important role in the world energy matrix in the future (SILVA JÚNIOR, *et al*., 2023).

During the 1930s, mixture of anhydrous ethanol in gasoline started, which was even more intensified with Proálcool program during the 1970s (ARAÚJO; ARAÚJO SOBRINHO, 2020a). The energy crisis in 1973 led the Brazilian State to invest in other energy matrices in order to reduce the dependence on oil derivatives (ARAÚJO; ARAÚJO SOBRINHO, 2020a). This strategy was intended to diversify the country's energy matrix, promoting the use of renewable sources like ethanol to reduce Brazil's vulnerability in relation to the shocks of the international petroleum market, and guarantee more energy safety (ARAÚJO; ARAÚJO SOBRINHO, 2020a). The introduction of anhydrous ethanol in the gasoline and the adoption of Proálcool represented important steps in the search for more sustainable energy alternatives and reduction in the dependence of fossil fuels in the Brazilian transport sector (ARAÚJO; ARAÚJO SOBRINHO, 2020a).

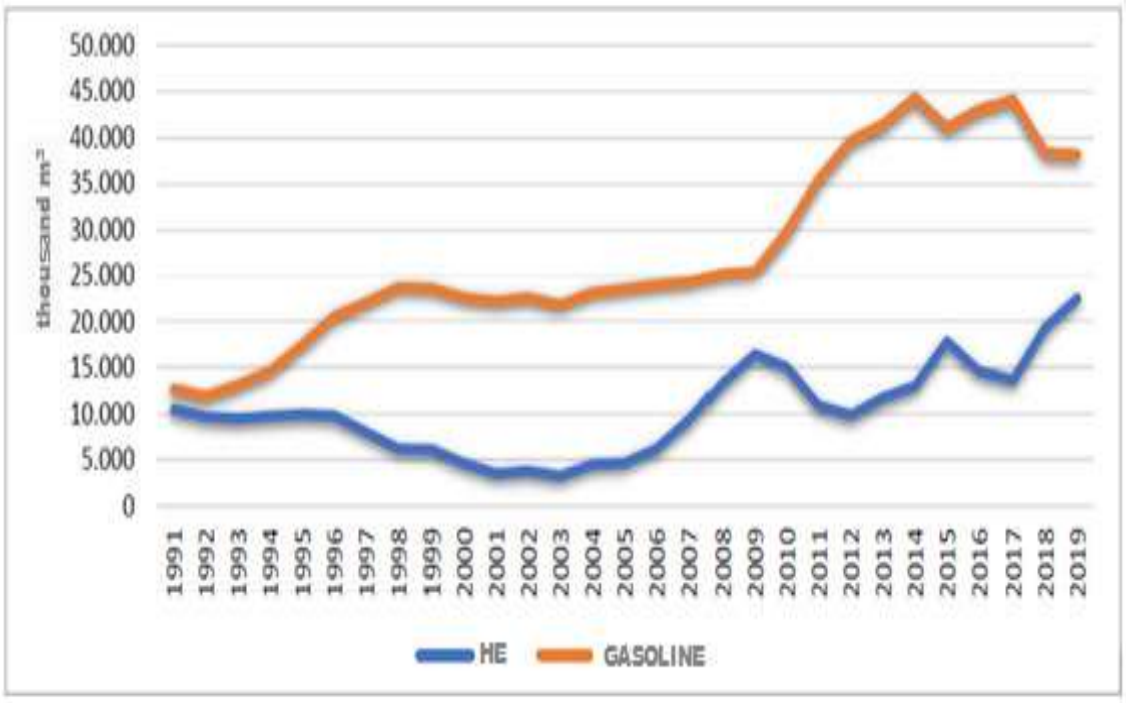
During the first decade of the 21st century there was growth in the adoption of biofuels, and ethanol in the market was outstanding, driven by the presentation of flexible motor vehicles (SILVA, 2021). That enabled the access by more people to this type of renewable and clean fuel. The change to biofuels is an important step in the fight against climate changes, and we hope that this trend will keep on growing in the coming years. In 2002, Ford presented the first flexible motor model in Brazil, more efficient than traditional motors, because it can run with different fuels, reducing costs and pollutants emission. the flexible motors are also more durable and require less maintenance (SILVA, 2021).

Volkswagen was responsible for inaugurating the wave of flex cars with the launch of the Gol model in 2003, which became a sales success and popularized the idea of a car running both with gasoline and ethanol. This Pioneer initiative paved the way for other manufacturers to launch their own models of flex cars, expanding the offer to consumers and consolidating the tendency of fuel flexible vehicles in the Brazilian automotive market. This technology has provided consumers with a more versatile and economic option of fuels, according to price variations and their availability. It has also contributed to diversify the country's energy matrix, reducing the dependence on

exclusive use of gasoline or ethanol, and promoting more flexibility in the choice of energy sources for mobility.

In 1991, gasoline C sold 17% more than ethanol, and this trend, favorable to gasoline C remained over the period analyzed, particularly in 2003, when ethanol sales fell and biofuel cars were launched. The superiority in volume of fossil fuel was over 83% in that year, according to data from the National Petroleum Agency (ANP, 2020). However, with the advent of biofuel cars, there was significant drive of Hydrous Ethanol Fuel (HEF) sales in Brazil, as clearly illustrated in Chart 01 below.

Chart 01- Sales of gasoline and HEF by distributors (thousand m³), 1991 – 2019 in Brazil



Source: ANP (2020) Prepared by the author (2023)

At the peak in 2009, HEF sales reached the record of 16.47 billion liters. However, this number was gradually reduced until 2012, when sales of 9.9 billion liters of hydrated ethyl alcohol (ANP, 2020). In 2015, the maximum amount of HEF was reached, 17.9 billion liters. In 2019, this record was broken with distribution of 22.5 billion liters of hydrated ethanol by distributors (ANP, 2020).

In 2005, Embraer surprised the aviation industry with the launch of the first agricultural aircraft powered by ethanol. In the following year, the company kept its

efforts in this area, expanding its ethanol powered aircrafts, so that 40& of its aircrafts in operation in Brazil were powered by this alternative fuel. In the year of release, 80% of the airplanes manufactured by the company were fueled with fuel alcohol, thanks to the technology they developed. This innovation contributed for the higher performance of aircrafts, with lower fuel consumption and pollutant emission, making of Embraer the leader in the aviation sector and reducing the impact of carbon footprint on the industry.

Meanwhile, biodiesel was taking the first steps. In order to drive its development and adoption, the government instituted the National Program for Biodiesel Production and Use (PNPB) in 2005, with law 11.097. PNPB establishes yearly targets for production and use of biodiesel in the country, in addition to encourage its use in public transport, which has contributed to make of Brazil, today, one of the main producers and consumers of this type of renewable fuel. According to Cortez *et al.,* (2016), this program established mixtures of biodiesel and common diesel, starting with 2% and reaching 7% in 2014, thus promoting the agriculture of plants and vegetable oil as raw materials for biodiesel production. The public policy also supported the use of biofuels in aviation by creating a program to replace up to 30% of fossil fuel with biofuels until 2030.

In the contemporary world, where concern with sustainability is growing, biofuel consumption has recorded significant increase. Brazil is outstanding in this sector, responding for almost 25% of the global consumption, right behind the United States, which holds 38% of the market (PRAUCHNER *et al.,* 2022). Currently, biofuels represent 4% of the world consumption, and bioethanol accounts for 2.44%, biodiesel 1.26%, and HVO 0.20% (PRAUCHNER *et al.,* 2022). Brazil is one of the main bioenergy producers worldwide, with bioethanol and biodiesel representing significant shares, 17.4% and 3.7%, respectively (PRAUCHNER *et al.,* 2022). This sector has grown expressively in the last years due to the advantage it offers against fossil fuels, like their renewable origin, lower environmental impact and more economy to the consumer.

During the 2010s, Brazil experienced expressive increase in the use of renewable energy sources, chiefly wind energy and biofuels. This success is the result of the inclusion of these alternatives in energy auctions, so that they could compete on

equal terms with other generating sources (CONTE, 2022). Moreover, the efficiency of wind turbines improved substantially in this period, making them increasingly competitive. These advances have contributed to make of Brazil world reference in clean and renewable energy generation (CONTE, 2022). As result, the participation of renewable sources in the Brazilian energy matrix reached 47.5% in 2020, exceeding the world average of 26.2% (MME, 2021).

In 2010, Petrolina Solar Energy Reference Center (Cresp) was inaugurated. It is responsible for installing one photovoltaic plant, in addition to conducting research to improve Brazilian plants and develop studies in solar energy. Over the years, Cresp was consolidated as reference in photovoltaic solar energy, attracting researchers and students from the whole country. The plant installed in Cresp is continuously monitored, and so researchers can assess and test different configurations to obtain the best possible performance. The results of this work are used to develop new technologies to be implemented in solar plants across the country.

Floating Solar Energy is an energy generation system that combines the sun strength with other sources, so that they can work together and provide continuous and efficient supply, better using the sun when its intensity is higher and resorting to the alternative source when the irradiation is weaker (CONTE, 2022). This system provides the rational use of the terrain and ensures continuous maintenance of energy, since it is possible to compensate the moments of production fall from one source to the other. In addition to the floating solar energy, Cresp also conducts studies on wind sources and hydrogen (ELETROBRAS, 2022), demonstrating its commitment with the research and development of sustainable technologies to the country.

The National Electric Energy Agency (ANEEL) published several Normative Resolutions. According to Pereira (2019), with Normative Resolution (REN) 481/2012 projects that used renewable sources between 30 and 300 MW, started until the end of 2017, could be benefitted with 80% reduction in tariffs for Use of the Transmission and Distribution System, valid for 10 years. After 2017, the benefits would remain, but reduced to 50%. ANEEL Resolution 482/2012 established criteria for the working of energy compensation systems, enabling small-scale energy generation like micro-generation and mini-generation.

Later, Resolution 687/2015 improved the previous procedures, simplifying the bureaucratic processes related to the approval of photovoltaic installations and integration of generating units to the electric power grid. However, there were adjustments of power limit to classify energy generation as micro-generation or mini-generation, and the sale of energy credits was abolished. However, the term for utilization of these credits was extended, and transfer to other localities is still allowed, as long as there is proof of ownership (PEREIRA, 2019).

The government implemented other advantages for renewable energy sources. In 1977 and 2015, the National Council for Finance Policy signed agreements that ensured tax exemptions for certain equipment used in solar and wind energy production, as well as the integration of these sources to the electric grid (PEREIRA, 2019). Moreover, the Special Incentive Regime for Infrastructure Development (REIDI) provides incentives to infrastructure projects like photovoltaic solar energy, exempting the contribution from the Social Integration Program, Civil Servant's Fund and the Contribution for Social Security Financing (PIS/PASEP/COFINS), in purchases and imports of machines, equipment, and construction materials for the fixed asset. This measure makes projects more competitive in the market and attractive for investments, playing an important role in the promotion of sustainable development in Brazil (PEREIRA, 2019).

The Program for Support to the Technological Development of the Semiconductor Industry (PADIS) provides incentives like reduction in PIS/PASEP/COFINS aliquots and Tax on Industrialized Products (IPI) in the purchase of machines and equipment by Legal Entities in the domestic market. Besides, consumers that generate their own energy from micro and mini-generation can be benefited with PIS and COFINS exemption. The Federal Government also decided to grant tax benefits to companies established in the Superintendencies of Development for the Amazon, Midwest, and Northeast until 2023, in order to promote the development in these regions, which present significant economic potential. So, companies installed in these areas can count on reductions in taxes and duties, which will make their business more competitive (PEREIRA, 2022).

To foster the Distributed Generation (DG) in Brazil, the Ministry of Mines and Energy (MME) created the DG Development Program (ProGD) in 2015, by means of

Ordinance 538. The program was designed to stimulate DG expansion with renewable sources and establish Working Groups (WG) to support DG implementation in public buildings. In addition to that, financial institutions offer credit lines with rates ranging from 0.9% to 1.3% a month to the electric sector, with emphasis on solar energy sources. These credit lines are essential for companies to invest in new technologies and remain competitive (PEREIRA, 2019).

Since 2010, incentives to the use of renewable energy sources and their inclusion in energy auctions resulted in significant increase in the use of these sources, particularly wind energy (FUGA, 2022). Though to a lesser extent, there was also growth in the use of solar energy. These measures have contributed to the greater diversification of the Brazilian electric matrix, making it increasingly sustainable and reducing its dependence on non renewable sources, like hydroelectric and thermoelectric plants.

Next we present statistics of investment in renewable energies in Brazil. These data enable the establishment of a parallel with the changes in the Brazilian energy matrix. After the analysis of these numbers, we can have a clearer notion of the courses the Brazilian electric sector can follow in the coming years.

Investments in renewable energies and the Brazilian energy matrix

In the previous section we saw a huge growth of internal offer of energy in Brazil. In 1990, the country counted on 142 million tons of oil equivalent (toe) – number that increased to 288.5 million toe (EPE, 2022). This significant increase in energy offer is fruit of the investment in new energy sources, like hydroelectric plants and wind farms. Though their expansion pace has suffered reductions, hydroelectric energy is still outstanding in the energy matrix. Hydroelectricity is one of the energy sources most used in Brazil. In 1990, 14.1% of the Brazilian energy offer was hydroelectric. This percentage rose to 15.8% in 2000, the highest number recorded so far (EPE, 2022).

After the 2001 Blackout, Brazil started to seek new energy sources to make up its matrix, since, in 2010, hydraulic energy still represented 14% of this matrix. During the 2010s, incentives to renewable sources and energy auctions were implemented,

which resulted in significant changes in hydroelectric energy participation in the Internal Energy Supply (OIE). According to EPE data (2022), hydroelectric energy participation fell to 12.6% due to the growing competitiveness of other sources, like solar and wind. However, hydroelectric energy is still an important source of energy in Brazil. These changes demonstrate the need of a more diversified and sustainable energy matrix in the country.

Since 1990, the participation of firewood and charcoal in the Brazilian energy matrix was considerably reduced, from 20.1% to 8.9% in 2020. This decrease can be attributed both to the growing energy efficiency and the replacement of these materials with other cleaner and less pollutant materials. Though the firewood and charcoal role in energy generation is diminishing, they are still important sources of energy for many people worldwide.

During the early 21st century, the increase in the Brazilian economy was followed by increase in the use of fossil fuel sources, which, in 1990, responded for 51% of the country's energy matrix, reaching its peak in 2001with 61% participation in the Internal Energy Supply (OIE). However, after this point, the contribution of these sources of energy started to decrease, reaching 53% in 2009. As of 2014, alternative energy sources started to increase more, reaching 61% participation in OIE. This rise can be attributed to the growing environmental awareness and policies for incentive to renewable energies. Still, the use of fossil fuels remains very high and represents a great challenge for future generations. In 2022, fossil sources still account for 51% of the Brazilian energy matrix, according to EPE.

During the 1990s, products from sugar cane recorded a slight decrease in their participation in the Brazilian energy matrix, according to EPE (2022). This reduction was 13.4% in 1990 to 10.9% in 2000, result of the growing distrust with regard to sugar cane fuel after the shortage of 1989 (ARAÚJO; ARAÚJO SOBRINHO, 2020b). After the first years of the 21st century, the curve tended to reverse due to the popularization of flex vehicles and agricultural aircrafts that use ethanol-based fuels. As result, in 2010, sugar cane products started to occupy 17.5% of the national energy matrix, reaching the peak of 19% in 2020, according to EPE (2022). Sugar cane is one of the main sources of renewable energy in Brazil and has great growing potential, mainly with the technological evolution (ARAÚJO; ARAÚJO SOBRINHO, 2020b). The use of sugar

cane to produce clean and renewable fuels like ethanol contributes to a more sustainable future (ARAÚJO; ARAÚJO SOBRINHO, 2020b).

During the 2010s, it was possible to notice the success of initiatives that drive the use of wind energy in Brazil. In 2010, it did not have participation in the Brazilian OIE, but, thanks to the expansion of projects for energy production over the years, its use grew substantially, reaching 1.7% of OIE in 2020 (EPE, 2022). Wind energy became one of the main sources of energy in Brazil and keeps on growing every year. According to the Decennial Energy Expansion Plan 2026-2035 (PDEE), prepared by the Ministry of Mines and Energy, wind energy participation in the Brazilian electric matrix is expected to reach 10% in 2025.

During the last decade, solar photovoltaic energy recorded accelerated growth, though there is still a long way to go for it to reach the same acceptance as that of the wind energy (SICA, *et al.*, 2018). In 2018, solar energy represented only 0.1% of the Brazilian electric matrix, but this participation rose to 0.3% in 2020, according to EPE (2022). Though the initial results were not exactly favorable, Brazil has shown great interest in the adoption of solar energy. Since 2012, the power installed of photovoltaic solar energy has substantially increased, going from 7 MW to 6.727 MW (SICA, *et al.*, 2018). This exponential growth in solar technology demonstrates the country's growing interest in clean and renewable energy. With the continuous reduction of solar cells cost, this number is expected to keep on growing in the coming years, bringing benefits to the environment and the global economy (SICA, *et al.*, 2018).

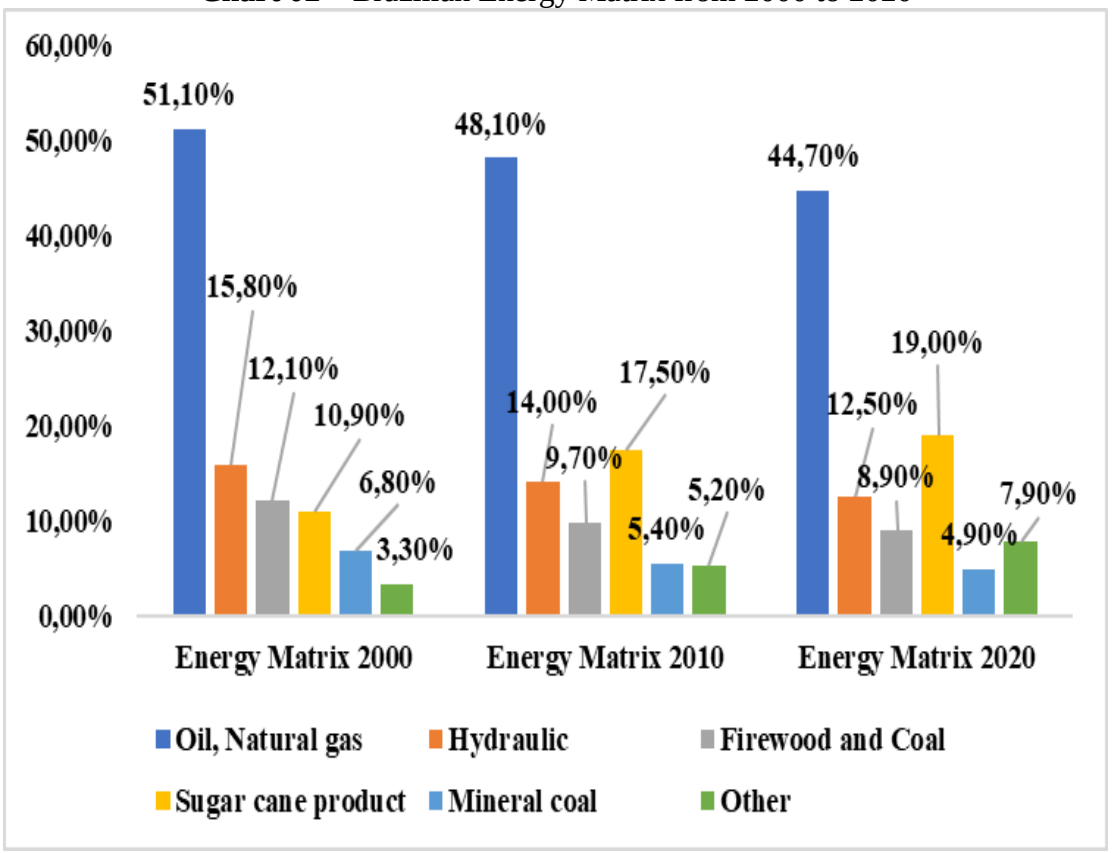
Since 2013, the solar energy price has dropped. According to Rigo et al. (2022), in the 2013 energy auctions, 1 Megawatt-hour (MWh) was worth US$103, while in 2019, this amount dropped to US$20.33, becoming one of the most affordable energy sources in economic terms. It means that more and more people have access to solar energy and can use it more efficiently. With costs ever lower, solar energy becomes an increasingly attractive option for people and companies interested in adopting renewable and more economic energy sources.

The increment of biomass in the Brazilian energy scenario is outstanding; its presence in 2000 was approximately 2%. During the following decade, this energy source gained even more relevance, consolidating its representativeness and reaching 8% of the Internal Energy Supply in the mid-2010s (EPE, 2020). Biomass is one of the

most promising renewable sources in Brazil, because it is abundant and can be used in several ways, including thermal, electric energy, or even for industrial purposes. Another factor that makes of biomass an excellent option is the fact that it doesn't emit pollutant gases in the atmosphere, different from most energy sources.

The "other" sector, which includes sources like nuclear energy, has grown at each decade. In 1990, it represented only 2% of the Brazilian Internal Energy Supply (OIE), having reached 3.3% in 2000 and 5.2% in 2010 (EPE, 2022). Recently, in 2020, nuclear energy represented 7.9% of the total energy matrix, according to EPE (2022). The transformation of the country's energy sources in the last years can be verified in the charts below. In the early 2000s, there was a great boom of wind energy, and after 2010, a major growth in solar energy generation occurred. This demonstrates that Brazil is increasingly diversifying its energy matrix and seeking cleaner and renewable options.

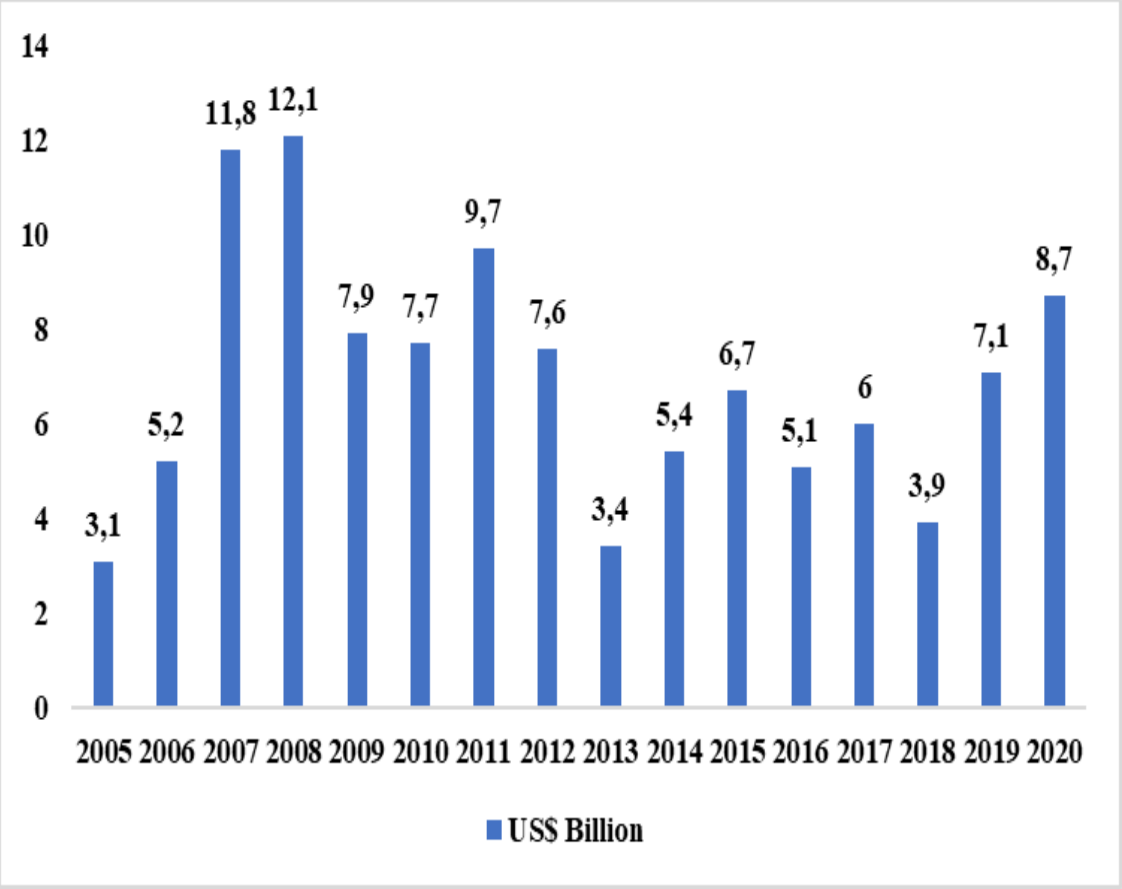
Chart 02 – Brazilian Energy Matrix from 2000 to 2020



Source: EPE (2022). Prepared by the author (2023)

In 2004, Brazil only invested around US$ 0.8 billion in renewable energies according to the Energy Research Company (EPE 2021). However, over the years, this value increased significantly. In 2013, the country had already invested US$ 7.6 billion in clean and renewable energies, demonstrating the country's commitment with the transition to a more sustainable economy. Though there was a high level of investments initially, expenses reduced to around US$ 7.9 billion in 2009, according to EPE (2022). The evolution of investments over the 2010s can be observed in the chart below, which shows constant fall in investments, reaching the lower value in 2015. That reflects the economic crisis that affected the world during that period. Fortunately, the situation improved in the last years, and investments are growing again.

Chart 03– Investment in Renewable Sources in Brazil – 2005 to 2020



Source: EPE (2022). Prepared by the author (2023)

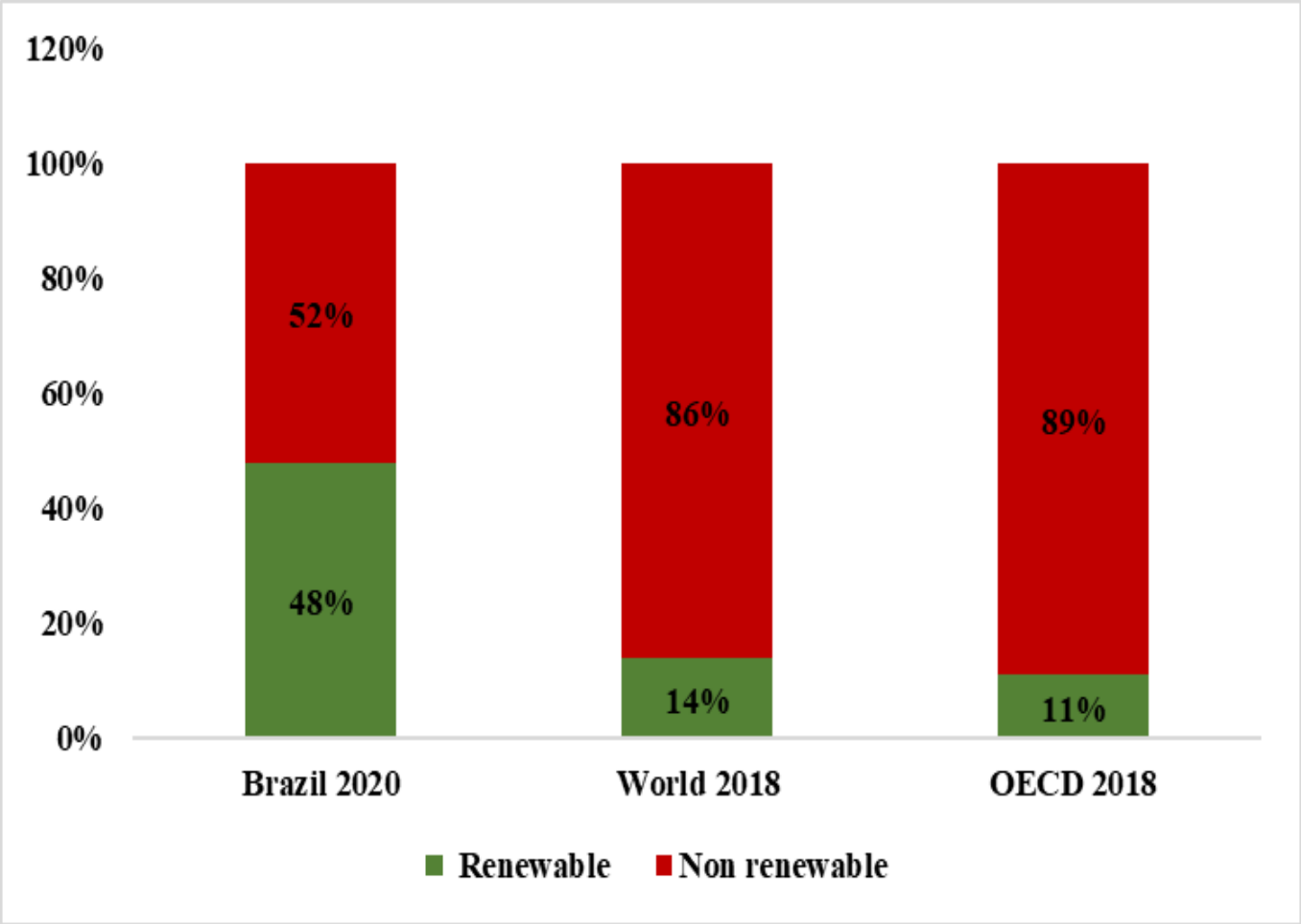
Though investments suffered oscillations over the years, in 2020 there was expansion in the injection of funds, event amid the pandemic, bringing refreshing results. Though the pandemic negatively affected the world economy, some companies could manage the situation and expand their businesses. The year 2020 demonstrated that, despite the adversities, it is possible to keep on growing and thriving. In 2022, Brazil was the Latin America country that invested more resources in renewable energies, with US$6.5 billion and 74% increase against the previous year, according to EPE (2022). This investment demonstrates Brazil commitment with the transition to a sustainable and low carbon economy. Moreover, these resources have led to substantial reduction of Brazil dependence on non renewable sources of energy, like petroleum and coal (EPE 2022).

In this perspective, it's important to examine how Brazil is dealing with its environmental targets and compare its performance with that of other nations. Brazil is a country with extensive natural resources and one of the largest economies in the world, but faces several environmental challenges, like Amazon rainforest degradation, deforestation, forest fires, and air pollution. Despite these problems, Brazil has significantly progressed in the improvement of its environmental situation through investments in renewable energies, like biomass, solar, and wind energies.

Assessment of the Brazilian energy policy and matrix

Brazil energy matrix is outstanding in relation to the global average, with renewable sources representing 49% of the whole energy consumed in the country in 2020, according to EPE (2022). However, to further advance in the use of clean and renewable energies, the country should implement public policies that encourage this type of energy source. Though having recorded over 40% of renewable energy in its energy mix since the 1970s, according to BEN 50 Anos (EPE, 2020), Brazil is still behind the average presented by OECD, which was only 5% throughout 2000. Though OECD countries have recorded considerable increase in the use of renewable sources in their energy matrix, which reached 15% of the total energy consumed in 2016, most of the energy comes from non renewable sources like petroleum and coal. Therefore, Brazil still needs to go a long way to reach a significant use of renewable sources.

Chart 04 – International comparison of renewable sources participation in the Internal Energy Supply (OIE)



Source: EPE, (2021). Prepared by the author (2023)

While India is outstanding as one of the largest emerging economies and China as an important world economic power, they both have huge demand for energy, which resulted in sharp reduction of renewable sources in their respective energy matrices. For almost four decades, the participation of renewable sources in India energy scenario was 60%, but this number fell to less than 40% during the 1990s and, currently, remains little above 20% (EPE, 2020).

However, in the last years, China has demonstrated greater commitment with the transition to a low carbon economy, with investments in renewable energy and ambitious targets to reduce greenhouse gas emissions. In 2020, the participation of renewables in China energy matrix increased to around 16%, with solar and wind

energies leading this growth (IEA, 2021). Though there is still a lot to do to substantially increase the participation of renewables in China and India energy matrices, these countries are taking important steps to deal with the climate crisis and reach a more sustainable future.

The Brazilian energy matrix, with higher use of renewable sources, is considered an important achievement in the fight against the increase in greenhouse gas emissions (GHG). The Nationally Determined Contributions (iNDC), a Brazilian government document that records the main commitments and contributions of Brazil to the global climate agreement negotiated and approved in Paris in 2015, was committed to reducing CO2 emissions emitted in 2005 until 2025, and the target is to cut these emissions by up to 43% until 2030. According to Küstner (2022), Brazil recorded 28% reduction in GHG emissions from 2005 to 2019. This progress is chiefly assigned to the significant reduction of emissions related to land use and deforestation since 2011 (KÜSTNER, 2022).

However, reaching reduction in carbon dioxide emissions in other areas is an extremely complex challenge. Moreover, the targets established by the Paris Agreement are considered insufficient to limit the global average temperature rise to 1.5ºC until the end of the century (SOARES; BARRETO, 2022). For this reason, the necessary changes must occur soon, requiring additional efforts by Brazil and all other countries to speed up emissions reduction. The urgency of actions is increasingly evident, as the world faces the harmful effects of global warming. It is crucial that all countries work together to reverse this situation before it's too late.

Though it is necessary to accelerate the progress in our country, Brazil presents favorable results in terms of greenhouse gas emission per inhabitant, when compared to other nations like India and China, and OECD. This is mainly due to the use of renewable energy sources like biomass and hydroelectricity. According to EPE (2020), in 2017, Brazil emitted less than a ton of CO2 per person, while in the same year, OECD, made up of European countries, and China generated carbon emissions superior to 5 tons per inhabitant, and the United States emitted little less than 15 tons per capita. This major reduction against the previous levels results from pollution control measures adopted by the country in recent years and increase in use of renewable energies. Thus,

despite the challenges faced, Brazil has potential to become world reference in sustainability.

Brazil has endeavored to drive the development of more sustainable renewable sources that cause low or no impact on nature and climate, as opposed to other forms, including large and small hydroelectric plants. These plants often present environmental issues such as greenhouse gas emission resulting from biomass decomposition in water reservoirs, displacement of local communities, and loss of biodiversity.

However, it is evident that Brazil has faced challenges to implement broader changes towards its environmental objectives, which demand efforts even more comprehensive than those already made. It's important to highlight the increase in the use of fossil fuels, which still have prevailing participation in the Brazilian energy matrix over the years. Such increase can be attributed to the growing energy demand, particularly in transport and industry sectors, poorly served by renewable sources. Besides, there are difficulties in the implementation of effective public policies that promote the use of alternative sources and the energy transition in the country.

Final remarks

Brazil, like other modern nations, depends on energy for its development. However, the current methods for energy production and consumption have caused significant damages to the environment and climate. So, the development of alternative sources of clean and renewable energy is increasingly urgent. In Brazil, solar, wind, hydroelectric energies, and biofuels are some of the renewable sources widely used. With the growing concern with climate changes, the discussion involving energy transition has gained momentum, leading to the implementation of targets for the growth of renewable energy participation in the energy matrix of countries and reduction in greenhouse gas emissions. Therefore, it is necessary to promote research and development of more efficient and sustainable technologies, in addition to stimulating the adoption of more conscious practices in terms of energy use and consumption.

Based on data available, though there are concerns and debates on the environment and climate changes in Brazil, it is clear that there was little progress, in

percentage terms, in the incorporation of renewable energy sources in the Brazilian energy matrix from 1990 to 2020. While analyzing the energy panorama in Brazil in these two years, we observed that only 49% of the internal energy offer comes from renewable sources, which represents the highest percent in this period. On the other hand, non renewable sources represented 51% of the energy matrix. That demonstrates Brazil's high potential to generate energy from renewable sources like biomass, hydroelectricity, and water resources.

The construction of dams to generate hydroelectric energy can result in flooding of large land areas, which can cause the forced displacement of entire communities, with significant social and cultural impacts. Moreover, the reservoir formation can lead to decomposition of submerged biomass, resulting in emission of greenhouse gases like methane, contributing to global warming. Another challenge faced by hydroelectric energy is the change in rivers' natural flow, which can affect fish migration, soil sedimentation and water quality. Vegetation suppression to build dams can also cause loss of habitat to the local fauna, resulting in loss of biodiversity.

Despite the problems associated to the construction of hydroelectric dams, this is still an important source of renewable energy in many countries due to their capacity to produce, reliably, and with low greenhouse gas emissions, when compared to fossil energy sources. However, adopting sustainable approaches in the construction and operation of dams, like mitigation of social and environmental impacts, monitoring and appropriate management of reservoirs, and investment in more advanced technologies to reduce negative impacts, is fundamental. The implementation of hydroelectric energy projects that consider active participation of local communities can be an alternative to minimize social impacts. Moreover, implementing hybrid energy generation systems that integrate different sources of renewable energy can help reduce the dependence on one single source of energy and increase energy efficiency in general.

It is worrying to notice that greenhouse gas emissions related to the energy sector have increased over the last decades, an increase of 2.02 times in 2020, compared to 1990. This fact is alarming, since the energy sector responds for around 80% of total CO2 emissions to the atmosphere. It is clear that we need, urgently, to make the transition to renewable energy sources, like solar and wind, as an effective way to fight

global warming. Investing in renewable energy sources is an essential strategy to reduce greenhouse gas emissions and mitigate the negative impacts of climate changes. Solar and wind energies, for example, are clean and abundant sources that do not emit pollutant gases and have minimum impact on the environment.

Therefore, diversification of the energy matrix using different renewable sources can increase the country's energy security, reducing the dependence on fossil fuels and promoting long term sustainability. To achieve this goal, promoting public policies that stimulate the use of renewable energy sources such as tax and regulatory incentives for installation of solar panels, wind farms and other forms of generation of clean energy is fundamental. Moreover, it is also important to invest in research and development of more advanced technologies aiming at increasing the efficiency and competitiveness of renewable sources. The transition to renewable energy sources not only will contribute to the environment preservation and reduction of greenhouse gas emissions, but will also drive the economy, generating jobs and promoting technological innovation. It is an urgent and necessary change to ensure a more sustainable and resilient future to present and future generations.

Given this scenario, understanding the trends of the Brazilian electric sector is increasingly important to ground strategic decision making. In addition to considering the contribution of economic activities to greenhouse gas emissions, it is also essential to compare these activities. That will enable the identification of the sectors that are the main responsible for the emissions, and, so, direct efforts to reduce them. A comparative analysis can also reveal opportunities for improvements in production processes, aiming to reduce greenhouse gas emissions.

It is highly important that studies are conducted in depth and with technical rigor, considering the particularities of the Brazilian context and the global targets for mitigation of climate changes. The transition to renewable energy sources is an urgent need, not only to reduce greenhouse gas emissions, but also to promote long term sustainability, drive the economy, and create job opportunities. Considering the integration of different renewable energy sources like solar, wind, biomass, and other is crucial to diversify the energy matrix and increase the system resilience. For such, the implementation of appropriate public policies like financial and regulatory incentives,

and the promotion of research and development of clean and efficient technologies are necessary.

Acknowledgements

I would like to thank the Coordination for Improvement of Higher Education Personnel (CAPES) for the financing granted, which made possible the conduction of this research. CAPES contribution was essential for this research success, and we are grateful for the support received.

References

AGÊNCIA INTERNACIONAL DE ENERGIA. **World energy balances: overview. França: AIE.** 2021. Disponível em: <https://www.iea.org/reports/world-energy-balances-overview/world>. Acesso em: 21 dez. 2022.

AGÊNCIA INTERNACIONAL DE ENERGIA. **World energy investment 2021**. França: AIE. 2021b. Disponível em: <https://www.iea.org/reports/world-energy-investment-2021>. Acesso em: 20 set. 2022.

ARAÚJO, D. F. C. de; ARAÚJO SOBRINHO, F. L. Agricultural culture of sugarcane in Brazil: contribution to the study of rural territories and their contradictions and conflicts. **Geopauta**, [S./l.], v. 4, n. 1, p. 162-183, 2020a. Disponível em: <https://periodicos2.uesb.br/index.php/geo/article/view/6303>. Acesso em: 24 apr. 2023.

ARAÚJO, D. F.C. de.; ARAÚJO SOBRINHO, F. L**.** A dinâmica do setor sucroenergético no Triângulo Mineiro/ Alto Paranaíba. **Revista Cerrados,** [S.l.], v. 18, n. 1, p. 248-277, 2020b. Disponível em: <https://www.periodicos.unimontes.br/index.php/cerrados/article/view/2527>. Acesso em: 28 nov. 2022.

BP. **Statistical review of world energy 2021**. London: BP, 2021. Disponível em: <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>. Acesso em: 23 set. 2022.

BRASIL. Lei nº 3.782, de 22 de julho de 1960. **Cria os Ministérios da Industria e do Comércio e das Minas e Energia, e dá outras providências**. Diário Oficial da União: seção 1, Brasília, DF, 22 jul. 1960.

BRASIL. Lei nº 3.890-A, de 25 de abril de 1961. **Autoriza a União a constituir a empresa Centrais Elétricas Brasileiras S. A**. – ELETROBRÁS, e dá outras providências. Diário Oficial da União: seção 1, Brasília, DF, 28 abr. 1961.

BRASIL. Lei nº 6.151, de 4 de dezembro de 1974. **Dispõe sobre o Segundo Plano Nacional de Desenvolvimento (PND), para o período de 1975 a 1979**. Diário Oficial da União: seção 1, Brasília, DF, 6 dez. 1974.

BRASIL. Lei nº 8.631, de 4 de março de 1993. **Dispõe sobre a fixação dos níveis das tarifas para o serviço público de energia elétrica, extingue o regime de remuneração garantida e dá outras providências**. Diário Oficial da União: seção 1, Brasília, DF, p. 2.597, 5 mar. 1993. PL 3497/1993.

BRASIL. **Ministério de Minas e Energia. Portaria** nº 538, de 15 de dezembro de 2015. Brasília, 2015.

CONTE, Karin Cristina. **Perspectivas e desafios do desenvolvimento da energia eólica *offshore* no Brasil.** 2022. 29 f. Monografia (Graduação em Engenharia de Energia), Universidade Federal de Santa Catarina, Araranguá, 2022.

CONVENÇÃO-QUADRO DAS NAÇÕES UNIDAS SOBRE MUDANÇAS CLIMÁTICAS. About the secretariat. Bonn, c2022a. Disponível em: <https://unfccc.int/about-us/about-the-secretariat>. Acesso em: 9 ago. 2022.

CONVENÇÃO-QUADRO DAS NAÇÕES UNIDAS SOBRE MUDANÇAS CLIMÁTICAS. **Conference of the parties (COP)**. Bonn, c2022b. Disponível em: <https://unfccc.int/process/bodies/supreme-bodies/conference-of-the-parties-cop>. Acesso em: 9 jun. 2022.

ELETROBRAS. 1962-2022: **Seis décadas de inovação**. Rio de Janeiro: Memória da Eletricidade. 2022. Disponível em: <https://heyzine.com/flip-book/dab8f7b013.html#page/1>. Acesso em: 20 nov 2022.

EPE, p. 452, 2016. Disponível em: <http://www.epe.gov.br/Documents/Energia%20Renov%C3%A1vel%20-%20Online%2016maio2016.pdf>. Acesso em: 12 jan. 2023.

EPE. **Atlas da Eficiência Energética Brasil**. 2020. Disponível em: <https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/atlas-da-eficiencia-energetica-brasil-2020>. Acesso em: 2 dez. 2022.

EPE. **BEN 50 anos**. [Brasília], [2020]. Disponível em: <https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/Documents/BEN%2050%20anos.pdf>. Acesso em: 2 ago. 2022

EPE. **BEN Interativo**. [Brasília], [2022]. Disponível em: <http://shinyepe.brazilsouth.cloudapp.azure.com:3838/ben/>. Acesso em: 26 dez. 2022.

FARIAS, C. G. de.; FONTGALLAND, I. L. **COMPLEXOS ENERGÉTICOS**: UMA ANÁLISE DA NOVA COMPOSIÇÃO DAS MATRIZES DE ENERGIA DO BRASIL E DO MUNDO. **Revista Ibero-Americana de Humanidades, Ciências e Educação**, [S. l.], v. 8, n. 1, p. 1421–1445, 2022. Disponível em: <https://periodicorease.pro.br/rease/article/view/3988>. Acesso em: 12 jan. 2023.

FERREIRA JUNIOR, Júlio Cesar Gomes; RODRIGUES, Manoel Gonçalves. Um estudo sobre a energia eólica no Brasil. **Ciência Atual: Revista Científica Multidisciplinar da UniSãoJosé**. Rio de Janeiro, vol. 5, n. 1, p. 2-13,2015.

FUGA, Fabiano Lúcio. **Produtos para potencializar a resposta da demanda no setor elétrico nacional**: aspectos conceituais, metodológicos, de modelagem e aplicação. 2022. 214 f. Tese (Doutorado em Sistemas de Potência), Escola Politécnica, University of São Paulo, São Paulo, 2022.

KRELL, Andreas Joachim; SOUZA, Carolina Barros de Castro e. **A sustentabilidade da matriz energética brasileira**: o marco regulatório das energias renováveis e o princípio do desenvolvimento sustentável**. Revista de Direito Econômico e Socioambiental**. Curitiba, v. 11, n. 2, p. 157–188, 2020.

Küstner, João Henrique. **Complexidade econômica e emissão de gases de efeito estufa**. 2012. 45 f. Monografia (Graduação em Ciências Econômicas), Universidade Federal de Santa Catarina, Florianópolis, 2022.

MAUAD, F. F., FERREIRA, L. d., & TRINDADE, T. C.. **Energia renovável no Brasil**: Análise das principais fontes energéticas renováveis brasileiras. São Carlos: EESC/USP. 2017.

OLIVEIRA, Talita. **Evolução da Matriz Energética Brasileira em Comparação com outros Países**. 2022. 55 f. Monografia (Graduação em Engenharia Química), Universidade Federal de São Carlos, São Carlos, 2022.

PRAUCHNER, Marcos J. *et al*. Alternative Hydrocarbon Fuels, with Emphasis on Sustainable Jet Fuels. **Revista Virtual de Química**, [S.L.], v. 15, n. 3, p. 1-21, 22 ago. 2022.

RIGO, P. D. et al. Competitive business model of photovoltaic solar energy installers in Brazil. **Renewable Energy**, [S./l.], v. 181, p. 39-50, 2022.

SICA, D. et al. Management of end-of-life photovoltaic panels as a step towards a circular economy. **Renewable and Sustainable Energy Reviews**, [S./l.], v. 82, part 3, p. 2934-2945, 2018.

SILVA JÚNIOR, D. J da.; SANTOS, W. G. B dos.; LOPES, R. S.; RIBEIRO, E. A. N.; SANTOS, W. J. C dos. Economizando eletricidade com aplicações sustentáveis diante de uma recessão na geração de eletricidade em meio a uma crise hidrelétrica no Brasil. **Investigação, Sociedade e Desenvolvimento**, [S. l.], v. 12, n. 1, p. e10012139638, 2023. Disponível em: <https://rsdjournal.org/index.php/rsd/article/view/39638>. Acesso em: 13 jan. 2023.

SILVA, Ubirajara Souza da Silva**. Etanol carburante no brasil**: Evolução, cenários e o seu desempenho sob os critérios da renovabio. 2021. 166 f. Dissertação (Mestrado em Engenharia Industrial), Universidade Federal da Bahia. Salvador, 2021. Disponível em: <https://repositorio.ufba.br/handle/ri/34845>. Acesso em: 2 dez. 2022.

SOARES, AM de A.; BARRETO, CG. Disputas e narrativas sobre a geração distribuída de energia elétrica no Brasil: retrocessos da Agenda 2030 para o desenvolvimento sustentável e do Acordo de Paris. **Sustentabilidade em Debate** , [S./l.] , v. 13, n. 3, p. 32–71, 2022. Disponível em: <https://periodicos.unb.br/index.php/sust/article/view/45621>. Acesso em: 13 jan. 2023.

TOMALSQUIN, M. T. **Energia Renovável**: Hidráulica, Biomassa, Eólica, Solar, Oceânica / Mauricio Tiomno Tolmasquim (coord.). – EPE: Rio de Janeiro, 2016. Disponível em: <https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-172/Energia%20Renov%C3%A1vel%20-%20Online%2016maio2016.pdf>. Acesso em: 13 jan. 2023.

Author

Daniel Féo Castro de Araújo – Degree in Geography and Master's Degree in Social Sciences from the Federal University of Uberlândia (UFU). He is currently PhD student at the Graduate Program in Geography from the University of Brasília (UnB).

Address: Universidade de Brasília - Campus Darcy Ribeiro - ICC Norte, Subsolo, Módulo 25. ZIP CODE: 70.904-970. Brasília - DF.

Article received on: February 07, 2023.

Article accepted on: May 04, 2023.

Article published on: August 01, 2023