Sustainable energy in Brazil: Challenges and opportunities for the coming years

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ABSTRACT

Over the last few decades, Brazil has demonstrated a privileged position in the global energy scenario. The country's energy matrix is diversified, with emphasis on the participation of renewable energies, which represent a significant portion of total energy production. Thus, the present research aimed to analyze the main challenges and opportunities for Brazil in the future as a potential energy generator. To this end, a literature review was carried out and, as a result, it was possible to verify that Brazil has opportunities and challenges in the sustainable energy sector. The main energy sources analyzed were hydroelectric, biomass, solar, wind and tidal. In this scenario, the diversification of the energy matrix, with a focus on renewable sources, is important to reduce greenhouse gas emissions and boost sustainable development in the country. The country has a biodiversity that contributes to the promotion of sustainable energies, such as an extensive coastline and regions with favorable winds, mainly in the Northeast and South. However, overcoming challenges such as start-up costs, infrastructure, and regulation is essential for the success of the

country's energy transition, which can attract investment, drive innovation, and strengthen global competitiveness.

Keywords: Energy, Sustainability, Brazil.

1 INTRODUCTION

Over the last few decades, Brazil has demonstrated a privileged position in the global energy scenario. The country's energy matrix is diversified, with emphasis on the participation of renewable energies, which represent a significant portion of total energy production. Hydroelectric power, for example, is one of the main sources used, taking advantage of the abundant hydraulic potential present in several regions of the country. In addition, biomass, wind energy and other renewable sources have gained space in the Brazilian energy matrix, contributing to the reduction of polluting gas emissions (DUPONT; GRASSI; ROMITTI, 2015).

As Bondarik, Pilatti and Horst (2018) point out, energy is a fundamental resource for the economic and social development of a country. In the global context, the search for sustainable and renewable energy sources has gained more and more prominence, due to concerns about climate change and the need to reduce greenhouse gas emissions. In this scenario, Brazil stands out as a major producer of energy, especially from renewable sources, such as hydroelectric, biomass and wind.

Hydroelectric power plays a key role in the Brazilian energy matrix. With a vast hydraulic potential present in several regions of the country, hydroelectric plants have been responsible for a significant portion of the total production of electricity. Brazil has large water reservoirs, such as those of the Itaipu, Belo Monte and Tucuruí power plants, which can generate significant amounts of electricity (JOURDA, 2016).

In addition to hydropower, biomass is another important source of renewable energy in Brazil. The country has a vast agricultural production, which results in a large amount of organic waste. These residues, such as sugarcane bagasse and agricultural crop residues, can be transformed into biomass and used for energy generation. Biomass plants have expanded in the country, contributing to the diversification of the energy matrix and to the reduction of polluting gas emissions (ALMEIDA; GUIMARÃES, 2022).

Wind energy has also gained significant ground in Brazil. With an extensive coastline and favorable wind conditions in several regions, the country has great potential for generating energy from wind. Wind farms have been built in different Brazilian states, especially in the Northeast, where wind conditions are more favorable. Wind energy has proven to be a viable and sustainable alternative, contributing to the country's energy matrix and to the reduction of greenhouse gas emissions (CUNHA et al., 2019).

In addition to these sources, other renewable energies are also gaining ground in Brazil. The country has been investing in technologies such as solar energy, biogas, and tidal energy, exploring

their potential in different regions. Solar energy, for example, has shown significant growth in recent years, driven by government incentives and the reduction in the costs of solar panels. This diversification of the Brazilian energy matrix contributes to increasing the country's energy security, reducing dependence on non-renewable sources, and mitigating environmental impacts (REIS; FATIGUES; CARVALHO, 2009).

According to Freire (2014), Brazil has faced challenges in the energy area, such as the need for investments in infrastructure and the search for sustainable solutions for energy generation and consumption. The transition to a cleaner and more sustainable energy model requires adequate public policies, incentives for the development of renewable technologies, and investments in research and development. However, the country has significant potential to further expand the use of renewable sources and play an important role in the global transition to a more sustainable energy matrix.

Brazil's prominent position as a major energy producer not only impacts the national economy, but also has environmental and social implications. The construction of large hydroelectric power plants, for example, can cause the displacement of traditional communities and generate significant environmental impacts, such as the flooding of environmental preservation areas. The use of biomass as an energy source, in turn, can generate concerns related to sustainability and the proper management of natural resources (DUPONT; GRASSI; ROMITTI, 2015).

In this context, this study sought to investigate, as a problematization, the following research question: "What are the main challenges and opportunities in Brazil in the coming years for the expansion and consolidation of a sustainable energy matrix, considering the available renewable sources and their environmental and social impacts?".

The proposed problematization is based on the need to understand the challenges and opportunities that Brazil will face in the coming years to promote the expansion and consolidation of a sustainable energy matrix. Although the country has a privileged position in the global energy scenario, with emphasis on the participation of renewable energies, there are a number of issues to be addressed to ensure the sustainability of this sector.

Thus, the present research aimed to analyze the main challenges and opportunities for Brazil as a potential future energy generator. To this end, the bibliographic research method was applied, which is, according to Gil (2011), a survey of documents already published, such as books, scientific articles, dissertations, theses, technical reports, among others, which address the theme in question. This research method allows obtaining up-to-date information based on previous studies, contributing to the deepening of knowledge on the subject.

Through this literature review, it is expected to contribute to the deepening of knowledge about Brazil as a major energy producer, highlighting its importance in the global energy scenario and the issues related to this position. The analysis of energy sources, their impacts and the public policies

adopted will allow a broader understanding of the opportunities and challenges faced in the Brazilian energy sector. In this way, strategies and guidelines can be identified for an efficient and sustainable management of energy resources, aiming at the economic and social development of the country, in line with the protection of the environment.

2 DEVELOPMENT

2.1 SUSTAINABLE ENERGIES AND OPPORTUNITIES FOR BRAZIL IN THE COMING YEARS

Sustainable energies, also known as renewable and clean energies, are those obtained from natural sources that regenerate or are virtually inexhaustible. Brazil has enormous potential for the development of sustainable energies in the coming years. The country is characterized by having a favorable climate, vast natural resources, and a growing demand for energy. The diversification of the energy matrix and the adoption of renewable sources have become strategic priorities for Brazil, aiming to reduce greenhouse gas emissions, increase energy security and boost sustainable development (LIMA, 2017).

One of Brazil's main natural resources is, according to Lopes and Taques (2016), its abundance of rivers and watersheds, which enables the generation of energy through hydroelectric plants. Hydroelectric power is already a significant source in the Brazilian energy matrix, representing approximately 60% of the installed capacity. The country's hydroelectric potential is still vast, with numerous opportunities for the construction of new plants and the use of small hydroelectric plants, especially in the Amazon region.

The Amazon has a large number of rivers and a favorable topography, which enables the implementation of medium and large hydroelectric plants. Projects such as the Belo Monte Hydroelectric Power Plant, located on the Xingu River, are examples of the region's hydroelectric potential. In addition to the Amazon, other regions of the country also have great potential for hydroelectric power generation. The rivers that cross the Brazilian territory, such as the São Francisco, Paraná, Tocantins, Madeira and others, offer favorable conditions for the construction of plants of different sizes. Hydroelectric power plants contribute to the stability of the national electricity system by providing clean, renewable, and low-cost energy (LOPES; TAQUES, 2016)..

Biomass is also a relevant opportunity for Brazil. The country is a major agricultural producer and has a vast amount of agricultural and forestry waste that can be used as biomass for energy generation. The production of biogas from animal waste and organic waste is also a promising area. The expansion of the use of biomass contributes to the use of waste, the reduction of emissions and the development of sustainable production chains (KITAYAMA, 2008).

The use of biomass as an energy source is a viable and environmentally friendly alternative, as it allows the use of waste that could otherwise become an environmental problem, such as crop

residues, tree bark, sawdust and sugarcane bagasse, among others. These residues can be transformed into solid, liquid or gaseous fuels for the production of heat, electricity or biogas (ALMEIDA; GUIMARÃES, 2022).

In addition, the production of biogas from animal waste and organic waste is another promising area in Brazil, as pointed out by Tachizawa (2011). The anaerobic decomposition of these materials generates biogas, composed mainly of methane, which can be used as fuel for the generation of electricity and heat. The expansion of the use of biogas contributes to the reduction of greenhouse gas emissions, since methane is a more potent greenhouse gas than carbon dioxide.

The use of biomass as an energy source offers several advantages. In addition to reducing dependence on fossil fuels and mitigating the environmental impacts associated with these fuels, biomass contributes to the development of sustainable production chains. The use of agricultural and forestry residues as biomass generates jobs in the production, transportation and processing chain of these materials (KITAYAMA, 2008).

Brazil has great potential to expand the use of biomass as an energy source, due to its vast agricultural and forestry production. This requires the development of efficient and sustainable technologies for the conversion of biomass into energy, as well as appropriate policies and incentives to promote their use. The expansion of biomass will contribute to the use of waste, the reduction of greenhouse gas emissions and the development of a more sustainable and circular economy (MIRANDA; MARTINS; LOPES, 2019).

In addition, it is worth highlighting Brazil's potential in relation to solar energy. The country has one of the best solar irradiations in the world, especially in the Northeast and Midwest regions. These regions are privileged with excellent solar irradiation conditions, which means that they receive high levels of solar radiation throughout the year (PINHO; GALDINO, 2014).

In the Brazilian Northeast, the solar incidence is, according to Machado and Miranda (2015), particularly favorable. The region is known for its tropical and semi-arid climate, with sunny days for most of the year. The dry climate and low cloud cover rates provide a high availability of direct solar radiation, ideal for the production of solar photovoltaic energy. Cities such as Fortaleza, Natal and Recife are among those with one of the highest rates of solar irradiation in Brazil.

The Midwest region, on the other hand, is characterized by a tropical climate, with well-defined seasons and a period of drought during the winter. These climatic conditions favor the generation of solar energy, since the sky is usually open and the solar incidence is intense during most of the year. Cities such as Brasília, Cuiabá and Goiânia have high levels of solar irradiation, making them suitable places for the installation of photovoltaic solar energy systems (PINHO; GALDINO, 2014).

From the perspective of Lana et al. (2015), the presence of these favorable conditions in the Northeast and Midwest regions of Brazil creates an environment conducive to the expansion of solar

energy. The abundant availability of solar radiation allows for the maximum use of photovoltaic solar energy, making it a viable and attractive source for electricity generation.

In addition, these regions are also known for their vast territorial extension, which makes it possible to install large centralized generation solar plants. These projects can take advantage of the availability of land and the favorable climate for the large-scale production of solar energy, contributing to the diversification of the energy matrix and the supply of electricity to adjacent regions (LANA et. al, 2015).

The expansion of solar PV has been significant in recent years, driven by a combination of factors such as reduced equipment costs, government incentives, and energy auctions. With the potential still untapped, Brazil can continue to grow as a leader in solar energy, both in centralized generation and in distributed systems (MACHADO; MIRANDA, 2015).

The Brazilian government has implemented incentives and public policies that stimulate the development of solar energy. Among these measures, Normative Resolution 482/2012 of the National Electric Energy Agency (ANEEL) stands out, which established the rules for the electricity compensation system, allowing consumers to generate their own solar energy and exchange the surplus with the local distributor (DUPONT; GRASSI; ROMITTI, 2015).

As pointed out by Reis, Fadigas and Carvalho (2009), another important factor for the growth of solar energy in Brazil is the energy auctions promoted by the government. These auctions aim to contract new renewable energy generation projects, including solar photovoltaics. With the competition among entrepreneurs and the search for competitive rates, auctions have boosted the expansion of solar energy in the country.

Wind energy also presents great opportunities for Brazil. The country has an extensive coastline and regions with favorable winds, especially in the Northeast and South. Brazil's extensive coastline, which stretches for more than 7,000 kilometers, offers a great opportunity for offshore wind energy exploration, i.e., offshore wind power generation. Coastal areas are known to experience strong and constant winds, which is ideal for the installation of offshore wind farms. These farms can be built close to the coast, where the sea depths are suitable for attaching wind turbines to bases on the seabed (MACHADO; MIRANDA, 2015).

In addition to the coast, Brazil also has regions with favorable winds in the Northeast and South of the country. The Northeast stands out as one of the regions with the greatest wind potential in Brazil. This region has constant winds, driven by the trade winds that blow from the Atlantic Ocean. States such as Bahia, Rio Grande do Norte, Ceará and Piauí have a large capacity for wind power generation, with wind farms already installed and in operation. In the South of Brazil, the states of Rio Grande do Sul and Santa Catarina stand out, which also have favorable winds for wind power generation. The

southern region is influenced by cold wind currents coming from Antarctica, creating favorable conditions for the installation of onshore wind farms (LANA et al., 2015).

Alves (2010, p. 165) emphasizes that:

> Faced with the global scenario of climate change, the importance of renewable energies is growing more and more in the spaces of government planning about their energy matrices. In Brazil, the wind potential has aroused the interest of several manufacturers and representatives of the main countries involved with wind energy. It is worth remembering that the Northeast region was one of the pioneers in the installation of wind energy for use in the generation of electricity. The facilities already in operation show an important initiative both by the Brazilian concessionaires responsible for the experimental projects and by the self-producing energy companies that, within the new scenario of the electricity sector, invest in the development of wind power for energy generation. For the field of wind energy development in Brazil, the figure of the self-producer and the independent producer are fundamental in the expansion of this sector, and in the promotion of a sustainable energy matrix.

The exploration of Brazil's wind potential has been driven by government incentives, such as wind energy auctions, which promote the contracting of new projects and enable the expansion of the sector. These initiatives have contributed to the significant growth of installed wind energy capacity in the country. The use of wind resources in Brazil has the potential to boost the economic and social development of the regions where wind farms are installed. The construction of these projects generates direct and indirect jobs, stimulates the local production chain and attracts investments in the areas of infrastructure and services (ALVES, 2010).

The installed capacity of wind energy has increased considerably in recent years, with successful auctions and technological advancements. The continuous expansion of wind energy contributes to the diversification of the energy matrix, reducing dependence on non-renewable sources and offering opportunities for job creation and regional development (NASCIMENTO; MARIE; CUNHA, 2012).

According to Nascimento, Mendonça and Cunha (2012, p. 647):

> [...] The environmental benefits that innovations in the Brazilian wind sector have been experiencing are related to the exploration of new sources of raw material for energy production, contributing to the reduction of polluting gases and reducing dependence on fossil fuels. In addition to structuring a complementary form for hydraulic energy, with a view to increasing the potential for wind energy production in periods of drought. It was also possible to verify that the institutional issues that govern the national energy system and the wind energy sector system have enabled and encouraged the feasibility of wind projects, highlighting the economic, environmental and social benefits that the strengthening of this industry can provide to the country.

Finally, it is worth mentioning the future opportunities that Brazil has in relation to tidal energy. Brazil has an extensive coastline, with a coastline that stretches for about 7,400 km. This represents great potential for tidal power generation. The North and Northeast regions of the country, in particular, have favorable geographical characteristics for the exploitation of this form of energy, with large areas of estuaries, bays and deltas (FISCHER, 2014).

The opportunities for Brazil in tidal energy in the coming years are significant. The country has a great potential for generating electricity from this source, which is still in the early stages of development. The implementation of tidal energy projects would bring several benefits, such as the diversification of the energy matrix, the reduction of greenhouse gas emissions, and the promotion of technological and industrial development (NETO et al., 2011).

According to Oliveira (2016), there are different technologies available for tidal energy generation. One of them is the installation of dams or dikes in favorable coastal areas, where seawater enters and leaves according to the tides. This movement of water drives hydraulic turbines that generate electricity. This technology is known as tidal energy of impoundage.

Another technology under development is the use of submerged turbines or tidal current turbines, which are installed on the seabed and capture the kinetic energy of ocean currents. This technology is known as tidal tidal energy. Brazil has great potential for the implementation of this technology, especially in the Amazon region, where the mouths of rivers generate strong sea currents (SESMIL, 2013).

However, it is important to highlight that tidal energy presents technical, environmental, and economic challenges. The construction of offshore structures requires significant investments and the technology is still in the development and improvement phase. In addition, careful environmental impact studies need to be carried out to minimise the effects on marine ecosystems (SILVA et al., 2018).

To seize the opportunities in tidal energy, Brazil should encourage research and development in this area, promote public-private sector partnerships, establish appropriate regulatory frameworks, and offer financial incentives. Collaboration with countries that already have experience in this form of energy, such as the United Kingdom and France, can be beneficial for mutual development and learning (TOLMASQUIM, 2016).

According to Fischer (2014), tidal energy can contribute to the diversification of Brazil's energy matrix, reducing dependence on non-renewable sources and mitigating the environmental impacts associated with electricity generation. In addition, the implementation of tidal energy projects can boost regional economic growth, generate jobs, and strengthen domestic industry.

2.2 SUSTAINABLE ENERGIES AND THE CHALLENGES FOR BRAZIL IN THE COMING YEARS

Brazil is a privileged country in terms of water resources, with a vast potential for the generation of electricity through hydroelectric plants. However, the development of this type of energy is not without significant challenges.

According to Freire (2014), one of the main challenges faced by hydroelectric power in Brazil is the environmental issue. The construction of large dams to create reservoirs can result in significant

environmental impacts, such as the displacement of local communities, the flooding of forest areas, and the loss of natural habitats. In addition, the formation of reservoirs can lead to the accumulation of organic matter and the consequent decomposition process, releasing greenhouse gases, such as methane, into the atmosphere. These environmental impacts are the subject of debates and controversies regarding the viability and sustainability of hydropower.

In addition, Lopes and Taques (2016) point out that another challenge to be considered is climate variability. Brazil is a country of continental dimensions and has different river basins, with different rainfall regimes. In years of scarce rainfall or hydrological imbalance, hydroelectric power generation may be compromised, resulting in a decrease in electricity production capacity. This can lead to the activation of thermal power plants, which use fossil fuels, increasing production costs and greenhouse gas emissions.

The over-reliance on hydropower also makes the sector vulnerable to extreme weather events, such as prolonged droughts or intense floods. In addition, hydropower requires large financial investments and a long construction time. The implementation of large hydroelectric power plants requires considerable resources, involving the construction of dams, turbines, transmission lines and associated infrastructure. These investments can be risky, as demand projections and energy prices can fluctuate over time, affecting the profitability of these projects. In addition, bureaucracy and environmental licensing processes can delay the construction and start-up of new hydroelectric plants (ALMEIDA; GUIMARÃES, 2022).

Another important challenge is the need to diversify the energy matrix. While hydropower is an important and renewable source, over-reliance on it can make the Brazilian energy sector vulnerable to fluctuations in water supply and the impacts of climate change. For this reason, it is essential to explore and develop other energy sources, such as wind, solar, biomass and even nuclear energy. The diversification of the energy matrix contributes to the security of supply and the reduction of dependence on a single source (NETO et al., 2020).

According to Lopes and Taques (2016, p. 91):

> With a water potential that represents more than 12% of the world's surface fresh water, conducive to the installation of hydroelectric plants and SHPs, disregarding the burden of the environmental impacts of its facilities, with the convenience of relying on sugarcane harvests in periods of drought, combined with the high incidence of winds on the north and northeast coasts, The lack of effectiveness of the Brazilian government's actions is evident. The Brazilian energy matrix, therefore, ends up concentrated in the use of fossil fuels and hydroelectric power, despite the favorable scenario for its diversification.

Biomass energy also faces some significant challenges in its implementation and expansion in the country. This is because one of the main challenges of biomass energy in Brazil is the availability and logistics of raw material supply. Although the country is rich in agricultural and forestry resources, the collection, transportation, and storage of biomass waste can be complex and costly. The energy

efficiency of biomass can also vary depending on the type of material used, the way it is processed, and the technology employed. Proper logistics and infrastructure are essential to ensure a continuous and sustainable supply of biomass (LOPES; TAQUES, 2016).

Tabatabaei and Ghanavati (2018) point out that another challenge is related to the environmental sustainability of biomass energy. Although it is a renewable source, burning biomass for power generation can generate greenhouse gas emissions such as carbon dioxide and nitrogen oxides. In addition, the expansion of biomass production can generate additional pressure on natural resources, such as forest areas and agricultural crops, which can lead to deforestation and biodiversity loss. It is essential to implement sustainable practices, such as the use of appropriate forest management techniques and the encouragement of biomass production from agricultural and industrial waste, in order to minimize environmental impacts.

It is also worth highlighting the economic competitiveness of biomass energy in relation to other energy sources. Production costs, especially those related to transportation, processing, and storage of biomass, can be high, affecting the economic viability of projects. In addition, uncertainty regarding stimulus policies and volatile fossil fuel prices may affect the attractiveness of biomass energy investments. A stable and enabling regulatory environment, along with adequate incentives, is needed to boost the development and competitiveness of this energy source (TABATABAEI; GHANAVATI, 2018).

The need for advanced technologies and investments in research and development is another important challenge in biomass energy in the country. The search for more efficient processes for converting biomass into energy, such as gasification and pyrolysis, can provide an increase in efficiency and use of resources. In addition, the development of carbon capture and storage technologies could further reduce emissions associated with biomass burning (UCZAI, 2009).

Lopes and Taques (2016, p. 92) argue that:

> The lack of effectiveness, therefore, is not a sign of non-evolution of environmental policies practiced in the country. Evaluating only actions, without analyzing their results, even though there are opportunities for the implementation of wind farms, greater incentives for ethanol, use of biomass, all of which can be used in a complementary way, it is possible to affirm that there is a concern in Brazil with its environmental policies and its sustainable growth. However, the advances in terms of policies and control do not reflect the inconsistent results, leveraged by the complexity in the definition of the set of energy sustainability indicators, and demonstrate at certain times that their complexity, despite all the incentives, inhibits investors and they spend energy on the means and not on the end goal.

As for solar energy, it faces several important challenges in Brazil. One of the main obstacles is the high initial cost of installing solar systems. While solar panel prices have decreased over time, considerable investment is still required to purchase and install a PV system. This makes it difficult for many people to access solar energy, especially those with low incomes (MACHADO; MIRANDA, 2015).

According to Almeida and Guimarães (2022), there is still a lack of awareness and education about the benefits of solar energy. Many people in Brazil are unaware of the technical aspects and the environmental and economic benefits of this form of energy. It is essential to invest in awareness and education campaigns to inform the population about the advantages of solar energy, highlighting its potential to reduce electricity costs and its positive impact on the environment.

Also according to the aforementioned author, Brazil faces challenges related to infrastructure and regulation. Connecting solar systems to the existing power grid requires investments in power distribution and transmission infrastructure. It is also necessary to establish clear and stable regulations that encourage distributed solar power generation and establish transparent rules for grid connection and compensation of excess generated energy. It is important to create an enabling environment for solar energy investments, with consistent policies and incentives that attract businesses and investors.

The variability of solar generation is another challenge to be addressed. Solar energy production depends on the availability of sunlight, which varies throughout the day and throughout the year. This requires the use of energy storage systems or supplementation with other energy sources to ensure a continuous supply. The expansion of energy storage capacity and the development of load management technologies are key to overcoming this variability and ensuring an efficient integration of solar energy into the country's electricity matrix (LANA et al., 2015).

Bureaucracy and permitting processes also pose significant challenges for solar energy in Brazil. Obtaining licenses and permits for the installation of solar systems can be a time-consuming and complex process, which discourages potential investors and hinders the growth of the industry. Simplifying and streamlining licensing processes, reducing bureaucracy, are measures that can boost the development of solar energy in the country (DANTAS; POMPERMAYER, 2018).

Regarding wind energy, Ferreira (2019) points out that infrastructure is one of the main challenges of this type of energy in the country. The construction of wind farms requires significant investments in terms of installing turbines, transmission grids, and energy storage systems. This infrastructure needs to be planned and implemented in an efficient manner to ensure that the energy generated by wind farms is integrated into the national grid in a stable and reliable manner.

It is also necessary to consider the availability of suitable areas for the installation of wind farms. Although Brazil has a huge wind potential along its extensive coastline and in some inland regions, it is necessary to identify locations with consistent and favorable wind speeds to ensure the economic viability of the projects. In addition, it is necessary to consider the environmental and social impact of these facilities, ensuring the preservation of sensitive areas and involving local communities in the development process (FERREIRA, 2019).

The issue of energy storage is also a major challenge for wind energy in Brazil. Unlike thermal or hydroelectric power plants, wind generation depends directly on wind conditions. This means that

energy production is intermittent and varies over time. Therefore, it is essential to develop efficient storage solutions, such as batteries or pumped storage systems, to address variability and ensure a continuous and stable supply of electricity.

The regulatory issue and incentive mechanisms are also challenges for wind energy in Brazil. Although the country has adopted policies to stimulate the expansion of renewable energies, such as energy auctions and the creation of the incentive program called RenovaBio, there are still bureaucratic obstacles and a lack of clarity in the rules and guidelines for the implementation of wind farms. A stable, predictable and favourable energy policy is key to attracting investment and boosting the sector (BARROSO, 2022).

According to Alves (2010, p. 186):

> As long as renewable technologies are at a small stage of development, with high cost and small market share, it is necessary to have a solid legal, regulatory and institutional apparatus in order to reduce risks for financiers. In addition to all these points raised, a change in the international context should be kept in mind, with the increase in the price of oil and the ratification of the Kyoto Protocol.

Nevertheless, the maintenance and operation of wind farms represent an ongoing challenge. Wind turbines are complex machines that require regular and specialized maintenance to ensure their efficiency and longevity. The lack of skilled labor and the need for adequate support infrastructure can affect the performance and availability of wind farms (ALVES, 2010).

Last but not least, it is worth mentioning the challenges for Brazil in the coming years in relation to tidal energy. Authors such as Fischer (2014) emphasize that there is a need for technology for the capture and conversion of tidal energy. There are different methods to harness this energy, such as tidal turbines, floating buoy systems, and wave energy systems. Each method presents its own technical complexities and requires significant investments in research and development to adapt them to the specific conditions of the Brazilian coast.

In addition to technology, there is a lack of adequate infrastructure for the installation of tidal energy projects, given that it is necessary to build structures such as dams, dikes, and power stations to capture and convert tidal energy into electricity. This requires careful planning and substantial investments in civil engineering (TOLMASQUIM, 2016).

Environmental permitting is a significant challenge for tidal energy projects. The process of obtaining environmental licenses in Brazil is known to be complex and time-consuming. Tidal energy projects involve environmental impacts and, therefore, must undergo rigorous evaluation to ensure sustainability and preservation of coastal ecosystems (TOLMASQUIM, 2016).

According to Neto et al. (2011), another point of attention is the cost of tidal energy. At the current stage of development, tidal energy projects can be more expensive than conventional energy sources. Initial investments are high due to the need for specialized technology and specific

infrastructure. However, it is important to highlight that as technology advances and the scale of production increases, costs are expected to gradually decrease.

An additional challenge is the integration of tidal energy into the existing power grid. Tidal energy is intermittent, depending on the tidal cycle, which requires energy storage systems or a flexible power grid capable of handling generation variations. Construction of transmission lines and upgrading of electrical infrastructure may be necessary to accommodate tidal energy efficiently and reliably (NETO et al., 2011).

Finally, another challenge faced by tidal energy in Brazil is public awareness and acceptance. Most people are not yet familiar with this renewable energy source and may have concerns about the environmental and socioeconomic impacts of the projects. It is essential to educate the population about the benefits of tidal energy, as well as to promote dialogue and public participation to ensure the necessary support for the development of these projects.

3 FINAL THOUGHTS

Based on the accomplishment of this bibliographic research, which aimed to analyze the main challenges and opportunities for Brazil as a future potential generator of sustainable energy, it is possible to conclude that the country has a solid and favorable base for the development of renewable sources in the coming years. The diversification of the energy matrix, with an emphasis on sustainable energies, is an important strategy to reduce greenhouse gas emissions, increase energy security and boost sustainable development.

Hydroelectric energy emerges as a significant source in the Brazilian energy matrix, with an enormous potential for use, especially in the Amazon region. The construction of new power plants and the use of small hydroelectric plants can contribute to the stability of the national electricity system by providing clean, renewable and low-cost energy. However, such energy faces challenges related to environmental issues, climate variability, large investments and bureaucracy.

Biomass also stands out as a relevant opportunity for Brazil, which has a vast amount of agricultural and forestry waste. The expansion of the use of biomass for energy generation will contribute to the use of waste, the reduction of emissions and the development of sustainable production chains. As challenges, biomass energy faces obstacles regarding the availability and logistics of raw materials, environmental sustainability, and economic competitiveness. It is necessary to invest in advanced technologies, research and development to increase efficiency and reduce the environmental impacts of this energy source.

In the field of solar energy, Brazil has one of the best solar irradiations in the world, especially in the Northeast and Midwest regions. The abundant availability of solar radiation enables large-scale photovoltaic solar power generation, both in distributed systems and in centralized generation.

Government incentives and energy auctions have boosted the growth of this source, which has increasingly competitive costs compared to conventional energy sources. In the case of solar energy, it is necessary to overcome the challenges related to the high initial cost, lack of awareness, infrastructure and regulation.

Wind energy also presents great opportunities for Brazil, taking advantage of the extensive coastline and regions with favorable winds, especially in the Northeast and South of the country. Wind energy auctions have stimulated the expansion of the sector, contributing to the diversification of the energy matrix and to the economic and social development of the regions where wind farms are installed. However, the expansion of wind energy requires efficient planning, identification of suitable areas, development of storage solutions, and clear regulatory policies.

Finally, it highlights the existing opportunities and challenges in relation to tidal energy, which emerges as a promising future opportunity for Brazil, due to its extensive coastline. The exploitation of this form of energy is still at an early stage of development, but it has the potential to diversify the energy matrix, reduce greenhouse gas emissions, and boost technological and industrial development. However, this energy requires technological advancements, adequate infrastructure, and appropriate environmental licensing processes.

In short, addressing the challenges related to sustainable energy in the coming years requires a comprehensive approach, which involves diversification of the energy matrix, technological improvement, investments in infrastructure, and adequate regulation. The search for sustainable solutions and the development of a resilient and efficient energy sector are essential to ensure energy security, reduce environmental impacts, and boost Brazil's economic growth in the global context.

The search for sustainable solutions and the development of a resilient and efficient energy sector are essential to ensure energy security, reduce environmental impacts, and boost Brazil's economic growth in the global context. By investing in sustainable energy, the country will be able to reduce its dependence on fossil fuels, mitigate climate change, improve air quality, and create green jobs. In addition, the transition to a cleaner and more diversified energy matrix can attract foreign investment, boost technological innovation, and strengthen the country's competitiveness on the international stage.

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