

Wind Energy in Brazil: Present Trends and Future Scenarios

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Abstract— Wind energy is becoming one of the main energy sources of the Brazilian Power Sector. The installed capacity increased from 247,00 MW in 2007 to 15.378,85 MW in 2019. This paper aims to examine the current scenario and the perspectives for wind energy in the country, based on an analysis of the institutional framework that developed the wind power sector in Brazil. In order to do this, this study carries out an analysis on two mechanisms that fostered this sector in Brazil: The Incentive Program for Alternative Energy Sources and the Auction of Alternative Sources, based on official data, legislation and specialized literature. The Incentive Program for Alternative Energy Sources enabled the acquisition of many wind farms, as it introduced local content rules. In addition, due to the prices that resulted from generation auctions in recent years, the extreme competitiveness of wind energy in Brazil becomes evident.

Keywords— Wind Energy, Public Policies, Brazil, Auctions, Competitiveness.

I. INTRODUCTION

In Brazil, the development of the power sector was strongly based on large hydroelectric plants with extensive water reservoirs. However, due to the intensification of environmental pressures and the depletion of water potential, the diversification of the Brazilian electrical matrix became urgent. To achieve this objective, one of the main actions was the expansion of national wind farms. According to the Energy Research Company (EPE), from 2007 to 2019 the installed capacity of this source increased from 247,00 MW to 15,378.85 MW, which represents an impressive average annual growth of 40.74% from 2007 to 2019 (EPE, 2020).

This expansion allowed the expressive increase of the participation of wind energy in the national electricity matrix, accounting for 9.0% of the Brazilian matrix in 2019, and thus the third energy source in terms of installed capacity after hydropower¹ (60.5%) and thermal (24.2%) (EPE, 2020).

It is also important to note that the current trend of increase of wind generation in the total mix is progressive. In this sense, according to the Decennial Energy Expansion Plan

2029

(PDE 2029) (EPE, 2019a), the share of wind energy in the electricity matrix in 2029 will be 17.32% (39,475 MW). Therefore, it can be said that the wind energy will be one of the pillars for the sustainable development of the country.

The developed auction system manages to coordinate the expansion of wind energy generation and provides for the allocation of energy generated by them according to the demands of the distribution companies, which are verified through market projections. One of the ways that government promotes the installation of new generating units is through New Energy Auctions. It was through this type of auction that the greatest expansion of wind power generation in Brazil occurred, leading to an accumulated growth of more than 6,000% increase in the installed capacity since 2006 until 2019 (ANAEEL, 2020).

In addition to making feasible the acquisition of many wind farms, the Incentive Program for Alternative Energy Sources (PROINFA) introduced local content rules, with the objective of fostering the national wind-based industry. Moreover, considering the results of electric energy auctions carried out between 2005 and April of 2020, wind power proved to be very competitive in terms of price, as

¹ The hydropower is the total national installed capacity plus the 7.000 MW imported from the Itaipu International Hydropower, due to a contract between Brazil and Paraguay.

can be seen in table 1. Except for hydropower, wind energy was the most competitive source. Therefore, one of the factors responsible for the recent expansion of the wind power source in Brazil is its competitiveness in relation to the other energy sources.

Table 1: Auction's Average Price per Source (USD/MWh²) – 2005 to 2020

Source	USD/MWh
Solar	64.96
Thermal	61.26
Small Hydropower (from 1 to 30 MW)	56.19
Micro Hydropower (up to 1 MW)	55.79
Wind	42.67
Hydropower	36.60

Source: ANEEL (2020), IBGE (2020).

Given this context, the objective of this paper is to present the current scenario and perspectives of wind energy in Brazil, based on an analysis of the institutional framework that led to the development of this sector in the country. For this purpose, the study focused on two mechanisms that fostered the sector in Brazil: PROINFA and the Auction of Alternative Sources. To achieve this objective, this paper is structured in 5 sections, including this introduction. Section 2 discusses the methodology of the paper. Section 3 presents a brief overview of installed wind power capacity in the world and in Brazil, as well as the capacity factor. Section 4 presents the institutional framework for the development of the wind energy industry in Brazil, focusing on PROINFA and alternative energy auctions. Finally, section 5 presents the conclusions and some considerations.

II. METHODOLOGY

The introduction section of this paper provides a literature review on the latest specialized studies on wind energy, with an approach to the scenario of this source in the world and, specifically, in Brazil. In this case, a systematic review of the literature is characterized by required critical appraisal, in addition to a synthesis of the information collected (Sampaio; Mancini, 2007). Section 3 carries out an analysis regarding the installed capacity of wind energy in Brazil and in the world and concerning CF of this source in Brazil. A study was also carried out regarding the evolution of the sector in Brazil and in the world, as well as of the current

scenario and future perspectives for wind energy, based on data from specialized centers in the power sector, such as GWEC and EPE. In section 4, the institutional framework structured to foster this renewable source of energy was presented. Regarding public policies, this section of the article focused only on the PROINFA program, with an analysis based on legislation. PROINFA is the first incentive program, in terms of a targeted government policy, to stimulate wind energy in Brazil. In this same section, a study will be carried out on Alternative Source Auctions, mainly based on data from National Agency of Electric Energy (ANEEL). The analysis of real prices by source is one of the means to evaluate the competitive advantage of wind energy. For this purpose, official data from generation auctions was collected between 2005 and 2019 for each source. From this data, a weighted average of prices for the power auctioned at each auction was done and then updated by the Brazilian Broad Consumer Price Index (IPCA). Finally, to obtain the real prices by source, a weighted average of each auction was made considering the contracted total of each source in other rounds. The renewable auctioning system consists of the determination by ANEEL of the amount of energy that must be auctioned and produced from alternative renewable sources. It is a competitive system, in which the lowest values win the bids until the amount of energy initially fixed by the auction is completed. Subsequently, long-term contracts are signed with the winners.

III. EVOLUTION, CURRENT SCENARIO AND WIND ENERGY PERSPECTIVES

The use of the wind as a resource started with the discovery of the conversion of the mechanical energy generation into something useful. The simplest wind devices date back thousands of years, such as the vertical- axis windmills found on the borders of Persia (Iran) around 200 BC (Kaldellis and Zafirakis, 2011).

The use of wind for electrical purposes is relatively recent, dating to the late 19th century in Denmark and the United States, with the use of machines which generated electricity (Tester et al., 2005). A century later, when electricity was already heavily supplied by fossil fuels, the major energy input at the time around the world, the first oil crisis in 1973 led the USA government to support research and development for wind energy. In this context, wind energy emerged as a viable alternative from the 1970s onwards when the technology for the wind power construction was

² The mechanism used for calculating prices will be explained in the next section

fostered for the first time (Wizelius, 2015; Leung; Yang, 2012; Kaldellis; Zafirakis, 2011).

After 1990, the European market intensified its expansion, both in terms of new facilities and in terms of attracting parts and component manufacturers, as a result of strong incentives from local governments. The promotion of wind energy was based on old issues, such as energy dependency, and new ones, such as environmental concerns focused on reducing greenhouse gas emissions.

In the late 1990s and early 2000s, the wind energy market began to spread around the world, no longer being concentrated only in Europe and the USA. In this sense, new facilities and manufacturers emerged in Asia (mainly India and China) and, still in an embryonic way, in Latin America and Africa. Since the mid-2000s, wind energy was already consolidated around the world, becoming a competitive renewable energy source in the last decade with a significant contribution to the reduction of greenhouse gas emissions (EPE, 2016).

In this sense, economic competitiveness is a key factor for the development of wind energy and its catching-on process (Farris, 2017). Even without public policies to encourage this source, wind energy is becoming cheaper than coal in several countries, resulting in an energy transition in countries such as the United States, China and India (Lucena; Lucena, 2019). Furthermore, due to meteorological variations in wind availability, energy storage is also an important issue of increasing interest for several countries (Stiebler, 2008).

Wind energy is known as a clean generation source, which takes up relatively little space and can produce energy in remote locations, as well as being a rich resource due to its presence in several locations (Lucena; Lucena, 2019). In addition, wind energy technologies can produce up to 10 times more jobs per MW of installed capacity than conventional fossil and nuclear-based generation energies (Sovacool; Watts, 2009).

The wind industry's production chain consists of the wind turbine and infrastructure items in the wind farm, such as foundations, transformers, substation, cables and inverters (ABDI, 2014).

The wind turbine is a fundamental item, as it represents approximately 60% of the total investment in construction and converts kinetic energy of winds into electricity. It is a complex and large machine with capacities ranging from 1.5 to 3 MW (ABDI, 2014).

Wind turbines have differences in terms of technology, which can be classified according to four criteria: (i) speed of rotation; (ii) force regulation or control mechanisms; (iii) drive train; and (iv) type of generator.

In addition to the cost of building turbines, there is a cost regarding transmission lines structuring, network connection and for aligning the foundations, access roads and paying lease to landowners (Farris, 2017).

Considering that wind speed can vary significantly over short distances, the procedures for assessing the location in which wind turbines are to be installed must take into account all locational parameters that influence wind conditions. Among the main influencing factors in the wind regime, the following stand out (Montezano, 2012): variation of speed according to the height; roughness of the land, characterized by vegetation, land use and buildings; presence of obstacles in the nearby areas; conditions of the ground, which can cause an acceleration or deceleration effect on air flow.

The different types of energy sources have diverse impacts on the environment. Fossil energies deplete natural resources and have significant environmental impacts. On the other hand, wind energy is relatively clean, producing less impact than conventional sources of energy generation (Wessier, 2007; Leung; Yang, 2012; EWEA, 2009). In this sense, wind energy plays an important role in combating climate change by reducing CO₂ emissions in generation (EWEA, 2009). In addition, the incentive to wind energy and other renewable sources has a fundamental role in stimulating energy security, making the country less dependent on other energy supplying countries (Lucena; Lucena, 2019).

In general, the cost of producing conventional electricity is determined by the following components: fuel, CO₂ emissions, operation, maintenance and capital. Depending on several factors, such as turbine size, available resources at the site and the operation method, a turbine pays back the energy that has been used to manufacture it in 3-9 months (Wizelius, 2015).

3.1 Installed capacity of wind energy in the world

The use of wind energy for power generation has grown exponentially in the world in recent years. The installed capacity worldwide was 24 GW in 2001, and in 2019 global capacity increased to 651 GW, representing an average growth of 20.33% per year (GWEC, 2020), which is presented in Figure 1.

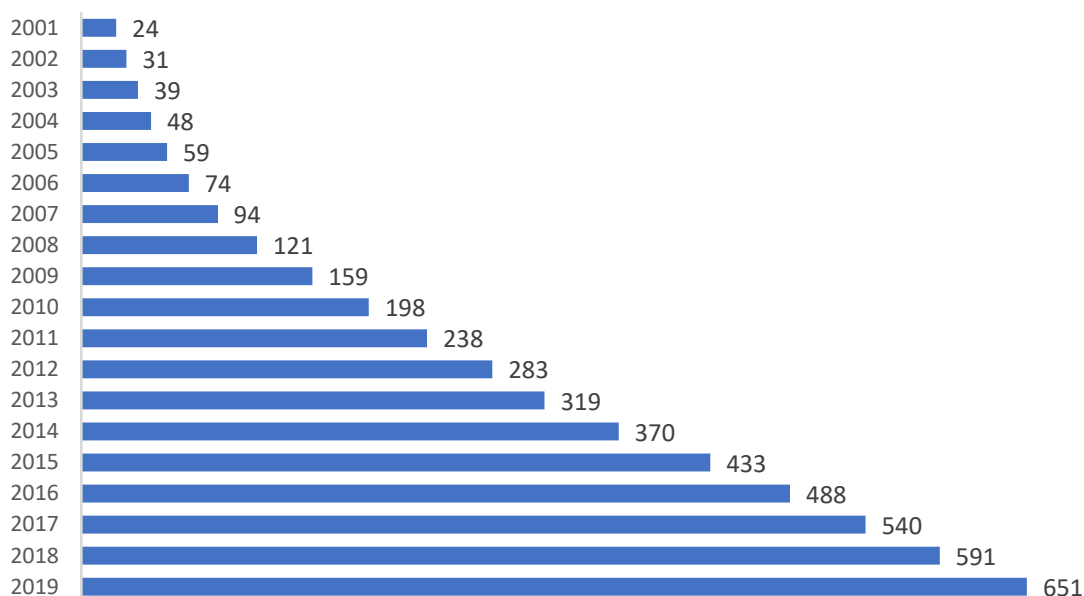


Fig.1: Evolution of the Global Installed Capacity (GW) – 2001 to 2019

Source: GWEC (2020).

Most wind turbines are installed on land (onshore), but a rising number of wind farms have been deployed offshore due to the decrease in appropriate land sites for new ventures (notably in Europe), even though they have higher costs. Of the total installed capacity worldwide in 2019, 83.80% is in only four countries, the two largest being China (36.34%)

and United States (20.82%). Brazil ranks eighth place, with 2.38% of the world's total, consolidating the country in a prominent position in a global scene. Figure 2 shows the top ten countries in terms of installed capacity regarding wind power.

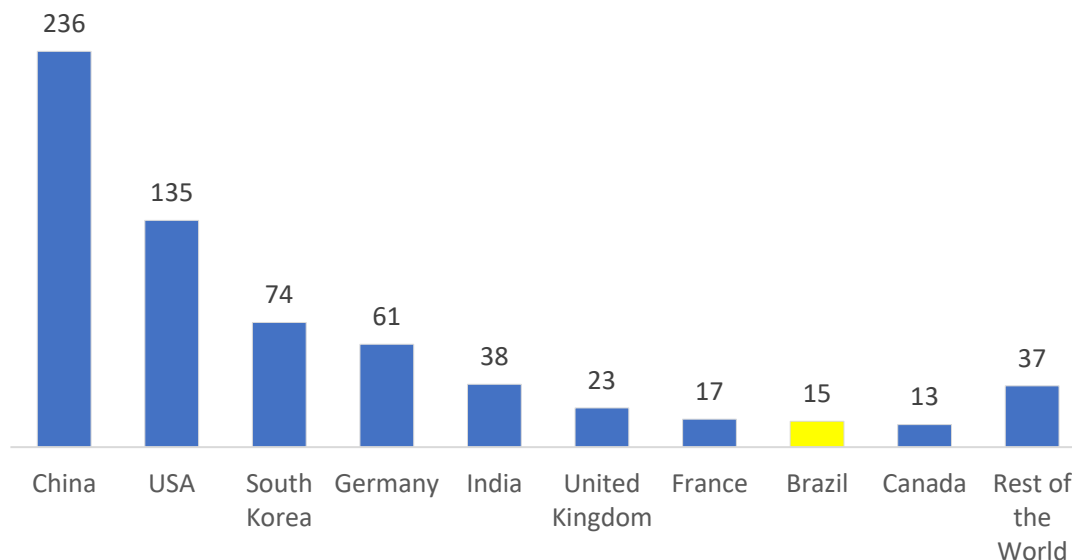


Fig.2: Installed Capacity (GW) by Country - 2019

Source: GWEC (2020).

It should be noted that the exponential growth of wind farms in the world was the result of policies for the promotion and

insertion of renewable energies, such as those adopted in the European Union (European Parliament and Council of the

European Union, 2001; 2009), and the implementation of different mechanisms of support such as tax cuts for renewables, carbon credit, carbon rates, price systems (i.e. feed-in tariffs), quota systems (i.e. renewables auctions) (Butler and Neuhoff, 2008; Couture et al., 2010; Ringel, 2006; Saidur et al., 2010).

Of all the mechanisms used, the most prominent was the feed-in tariff, adopted by at least 78 countries, including the five leaders in installed capacity (EPE, 2016; REN21, 2015). In countries where feed-in tariffs exist, utilities are compelled to permit wind parks to connect to the grid, as well as to pay a minimum fixed price for the renewable energy supplied by entrepreneurs (Stiebler, 2008; Mello, 2013). Feed-in support policies have proved very effective in stimulating the growth of renewables; however, auction schemes have gained popularity between 2010 and 2015, specially in developing countries due to their need to stimulate the implementation of renewable sources because of growing demand and to ensure lower energy costs (EPE, 2016).

The growing interest in auctions is driven by their ability to implement renewable energy according to the needs of the system in a planned way, with several advantages, such as: flexibility, the ability to guarantee greater security in price and quantity, and the transparency of the process (IRENA; CEM, 2015).

3.2 Installed capacity of wind energy in Brazil

The participation of wind energy has increased in the national electricity matrix, rising from 0.25% (237 MW) in

2006 to 9.04% (15,378.00 MW) in 2019 (EPE, 2020).

The main Brazilian study developed with a focus on the expansion of the power sector is the Decennial Energy Expansion Plan (PDE), produced by the Energy Research Company (EPE). Since the PDE is an indicative study, the amount and technological composition of the generation capacity expansion indicated in this document does not directly determine the investments that will be made in the generation system. Therefore, this means that generation expansion decisions are ultimately determined by decisions of agents in a market environment, through energy auctions and by contracting free market expansion. For example, the demand to be contracted is provided by market agents who may use projections different from those stipulated in the PDE (EPE, 2017). According to PDE 2029 (EPE, 2019), the share of wind energy in the electricity matrix is expected to continue to grow, rising from the current 9.04% to 17.32% in 2029.

Figure 3 shows the relative share of each source in the matrix in 2019 (in blue) and 2029 (in red). It is expected that the wind energy will exceed the thermal energy source, in terms of installed power, thus assuming the second position in the Brazilian electricity matrix in 2029, only losing to hydropower. In addition, it is important to state that there is complementarity between the wind source and hydroelectricity, as periods of rain and wind are interspersed (Bittencourt et al., 1999). In addition, wind energy may contribute to reducing transmission losses and reinforcing the grid (Dewi, 2000).

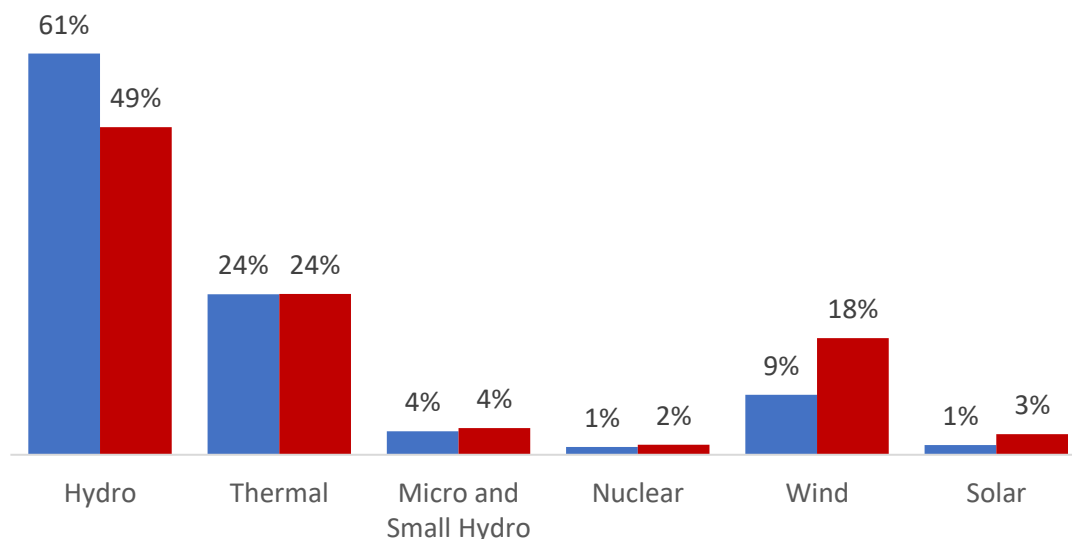


Fig.3: Share of Each Energy Source in the Brazilian Electric Matrix: 2019 and 2029

Source: Own elaboration with data from EPE (2020).

Figure 4 presents the evolution (actual and projected) of wind power in terms of installed capacity (GW). It is possible to analyze the expressive increase of wind energy

in between 2013 and 2018, period in which several parks began their operations and starting generating electricity.

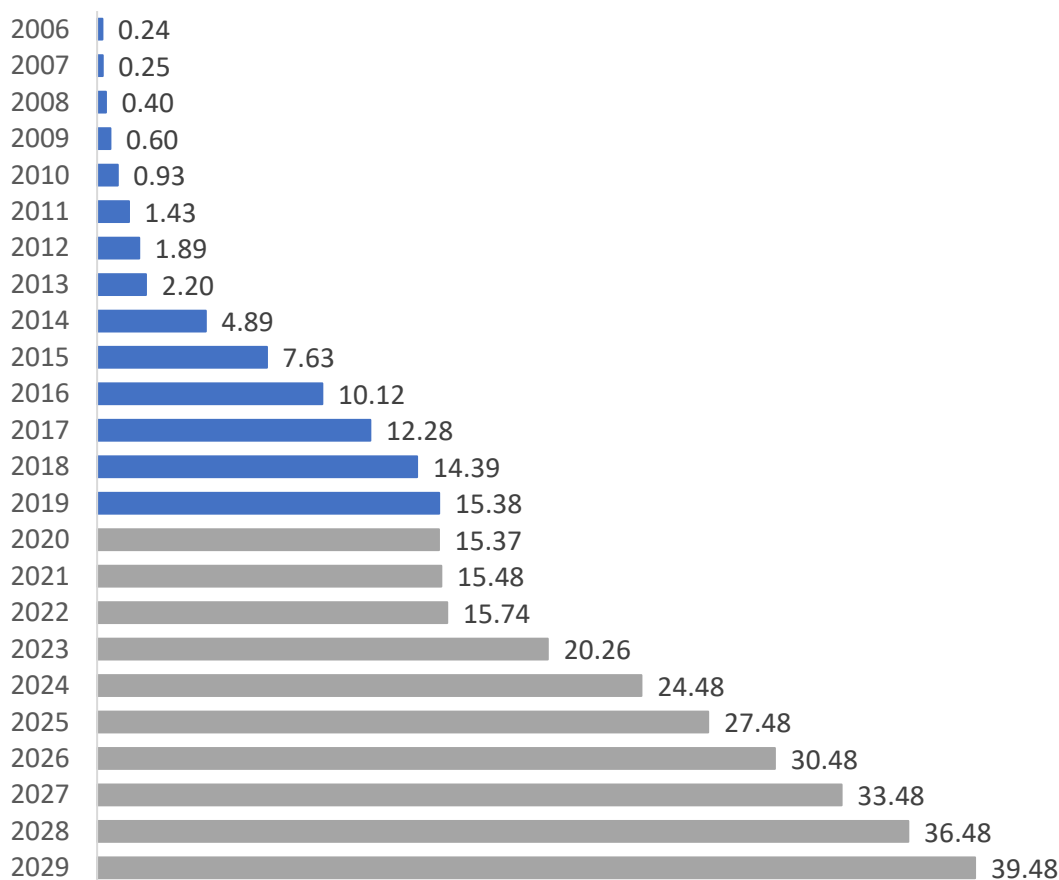


Fig.4: Evolution of the Brazilian Wind Installed Capacity (GW) – 2006 to 2029

Source: EPE (2016; 2019).

In 2018, the largest fraction of the installed capacity of wind energy (85.23% or 12,264 MW) is concentrated in the Northeast region. This region contains the cities with the lowest human development indexes. The wind energy chain generates several jobs for these cities, mainly during the construction period of the plants (Lucena; Lucena, 2019). Large groups that have established businesses in the Northeast region, with their compensatory and social responsibility policies, have fostered socioeconomic development in local communities (MME, 2015).

The Southern region represents a share of 14.58% (2,098 MW) and, with a marginal contribution, the Southeast region holds 0.19% (28 MW) of the country's installed capacity (EPE, 2019b).

In several cases, the construction of wind power plants must take place on private properties, and the construction authorization must come from the owner (Lucena; Lucena,

2019). Unlike hydroelectricity and gas production, wind energy does not pay compensation to states and municipalities, since the main beneficiaries of park facilities are landowners who receive leases for the use of land. In addition, for the installation of wind turbines, it is necessary to obtain authorization from local, municipal, regional and federal authorities, according to local, state and federal legislations and regulations (Lucena; Lucena, 2019).

In Brazil, many suppliers and manufacturers of wind turbine components have reached the market. In addition, a strong decrease in sales prices happened. The strategy of American and, mainly, European companies was to enter the Brazilian market aggressively, lowering prices and supplying cheaper equipment for the installation of manufacturing units in the country (Mello, 2013).

The competitiveness of the wind energy industry in Brazil can also be analyzed through the drop in average investment

value (total Capex), which was reduced by approximately 50% from 2005 to 2012. The initial value of USD 1.62 million per installed MW (PROINFA) was reduced to USD 943 thousand per installed MW in recent projects. This reduction is largely justified due to the technological revolution that the industry has undergone in recent years and, especially, due to the massive entry of wind turbine manufacturers, since 2009 (Mello, 2013).

3.3 Wind energy’s capacity factor in Brazil and in the world

Wind power’s capacity factor (CF) represents the ratio of actual unit generation to total capacity over a period. Therefore, CF can be interpreted as a measure of productivity. Worldwide CF has increased significantly due

to technological advances and increase in the size of facilities, which allows better appropriation of winds. In this context, Brazil has the highest average of CF in the world (MME, 2017), which can be seen in Figure 5. The Brazilian wind energy productivity of recent years has revealed an exceptional performance of the national generation matrix, with a higher CF index than other countries in the world, which reinforces the consolidation of this source in the Brazilian Power Sector (ABEEOLICA, 2018). In this sense, Brazil rose from a 32.42% FC in 2012 to 42.68% in 2019 (ABEEOLICA, 2020). On the other hand, the world average CF for 2016 was 24.7%, reinforcing the successful result obtained by Brazilian wind generation in recent years (MME, 2017).

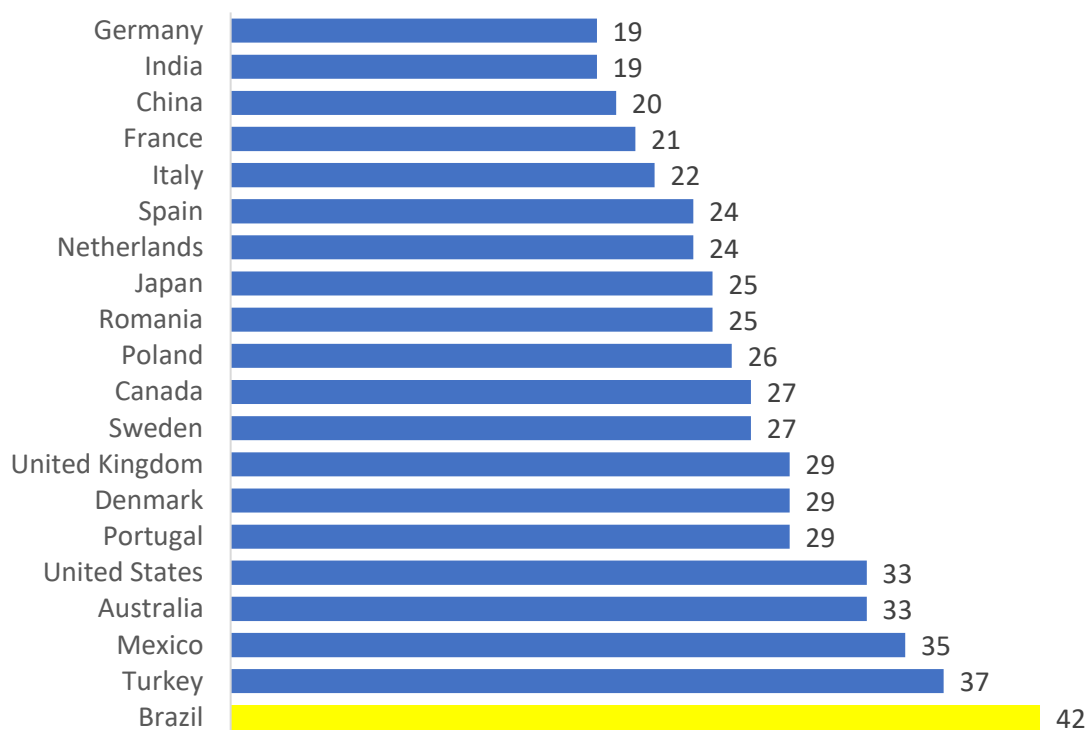


Fig.5: Average Capacity Factor by Country (%) – 2016

Source: MME (2017)

The characteristics of the country display that there is an immense opportunity of growth of the wind source due to the high generation potential still to be exploited; the high rate of usage resulting from geoFigure properties; the economic incentives for the source, such as exemption of taxes; discounts of tariffs; and exemptions on distributed generation.

The seasonality of the wind power source in Brazil leads to

an increase of CF in dry months, from May to November, with a decrease in the wet months, between December and April. Figure 6 shows the average, maximum and minimum annual Brazilian CF. It can be affirmed that a positive aspect of this seasonality is its complementarity with the hydropower source, which concentrates part of the generation in the dry period of the year. This means that stimulating wind energy contributes to the national energy balance.

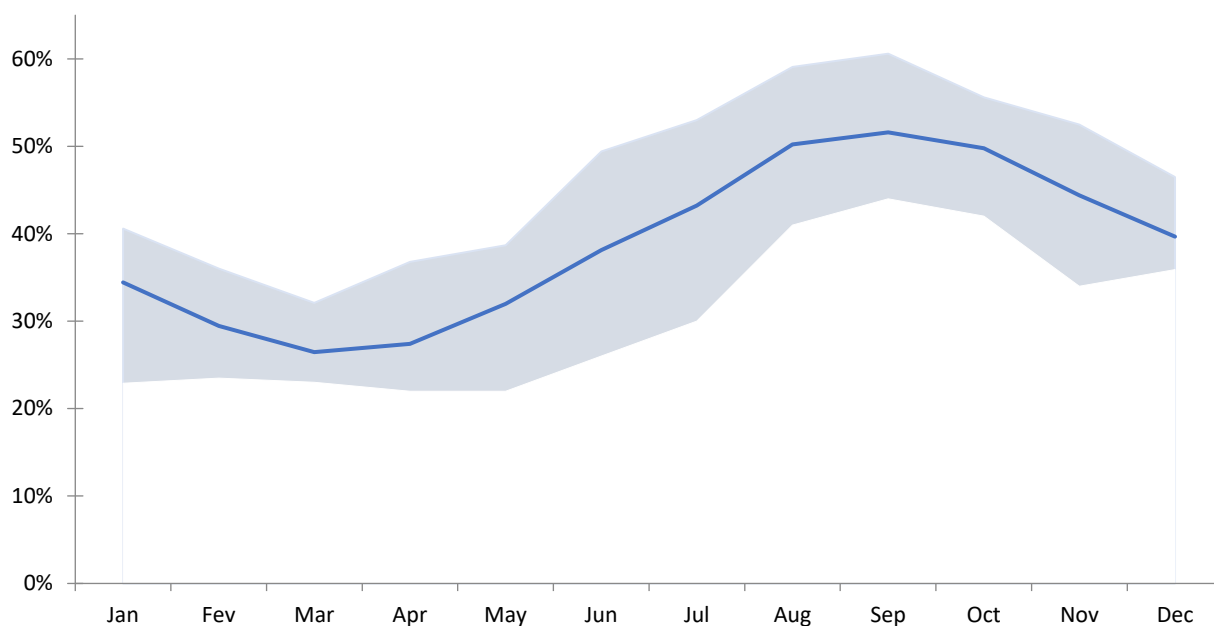


Fig.6: The Average, Maximum and Minimum Annual Brazilian CF – 2012 to 2019

Source: Completed with data from ABEEólica (2020)

IV. INSTITUTIONAL BACKGROUND

The energy thematic has become increasingly important in the Brazilian scenario, especially after the 2001 energy crisis. Since then, the Brazilian government has been concerned with diversifying the sources that make up the national energy matrix, seeking to increase the participation of alternative sources and, consequently, to foster security in electricity supply. As a result, the Brazilian government started to invest in programs that would encourage the production of electrical energy from other clean sources in addition to hydraulics (Tomalsquim, 2000; Pego Filho et al, 2001).

The legal framework and economic rules for the production, commercialization and distribution of energy are defined by the energy policies of national governments (Wizelius, 2015).

For the effective development of alternative sources, the State must create coordinated programs focused on each source to adequately stimulate its expansion.

After the detachment crisis between supply and demand of electricity in 2001, the current model of the Brazilian Electricity Sector (SEB) was created in 2004 through the ordinance of Decree No. 5.136/2004, regulating Law No. 10,848 /2004, which defined that the guiding principle of reasonable tariffs.

The auctions were created to make it possible to contract electrical energy at the Regulated Contracting Environment

(ACR) through price determination and the signature of Energy Commercialization Contracts in the Regulated Environment (CCEAR). The Ministry of Mines and Energy (MME) defines maximum auctions prices for existing projects. Through this methodology, generators receive a “fixed” revenue, based on the expected annual energy production (Mello, 2013). The objective low prices offerings in auctions forces investors to minimize investment, betting on the implementation of smaller wind turbines. Turbines with smaller generators and larger blades are cheaper, although they do not maximize the use of the local wind potential. As a result, these generators frequently operate close to the nominal capacity than the larger ones, having a lower MW ratio per local area and a greater capacity factor, which explains, in part, the high Brazilian capacity factor in wind energy, presented in section 3 of this article (Mello, 2013).

4.1 PROINFA

The first incentive to the wind power source began during the 2001 energy crisis, when the hiring of this type of generation in the country, hitherto insignificant, through the Emergency Wind Energy Program (PROEÓLICA) (Brazil, 2001). The program aimed at contracting 1,050 MW of wind energy projects by December 2003. However, the program did not achieve the expected results. In 2002, PROINFA was created by Law No. 10.438/2002. The main objective of

this program was to promote renewable energies³, diversifying the national electricity matrix and guaranteeing long-term supply of electric energy. More specifically, it sought to promote security of supply, valorization of regional and local characteristics, job creation, training of workers, as well as reducing greenhouse gas emissions (Brazil, 2002).

Initially, PROINFA was divided into two phases: the first for the implementation of short-term projects and the second for long-term implementation, with detailing defined by the law (Dutra and Szklo, 2006). In its first phase, PROINFA could be considered a type of feed-in tariff because it established specific values for commercialized energy by source for a period of 20 years (EPE, 2016). The costs of the program are recovered through a fee paid by the consumer through energy bills. In the case of wind energy, a base value of 46.56 USD/MWh was set, as well as a ceiling value of 52.81 USD/MWh (Brazil, 2004).

To facilitate the contracting of wind farms, the program introduced local content rules, aiming to foster the national wind-based industry as well as other sources involved in this. In addition to the feed-in mechanism, PROINFA presents an instrument of subsidies for investments by providing specific lines of credit of the Brazilian Development Bank (BNDES)⁴ for selected projects. PROINFA initially had up to 80% financing from BNDES and 3,300 MW of installed electricity produced from clean sources, with a nationalization index between 60 and 90% of the equipment and services used in power generation (Ferreira, 2008; Salino, 2011; Mello, 2013).

Currently, PROINFA continues to be an important government mechanism for the promotion of alternative renewable sources in the production of electric energy, by privileging entrepreneurs that do not have corporate ties with generation, transmission or distribution companies. The cost of this program, with energy acquired by Eletrobras, is paid by all final consumers of the National Interconnected System (SIN), except those classified as low-income.

PROINFA, with its maturation, elevated the country to an unparalleled level where currently non-conventional renewable energy sources are contracted without the need for subsidies, such as feed-in tariffs, used in other countries that invest in this source (Mello, 2013).

³ Small hydroelectric plants, wind power plants, and thermoelectric projects with biomass fuel.

⁴ Also known as the National Bank for Economic and Social Development is a federal public company, associated with the Ministry of Development, Industry, and Trade, with the goal of providing long-term financing for endeavors that contribute to the country's development.

Since the second phase of the Program was never regulated, energy auctions for the purchase and sale of energy became the main means of increasing the participation of alternative sources in the generation of electrical energy. Therefore, a new context for the promotion of wind energy in Brazil was consolidated with energy auctions.

4.2 Energy auctions

According to Da Silva (2011), the auctions promoted by the Electricity Energy Trading Chamber (CCEE) have become the main energy trading mechanism between producers and electricity distributors with the advent of the new Brazilian regulatory model after 2004.

Alongside PROINFA, another mechanism was implemented to stimulate the expansion and contraction of renewable sources: The Alternative Sources Auction (ASA). With energy auctions, a share of new renewable sources is negotiated in competitions⁵ promoted by the regulatory agency. In this case, the energy producer's subsidy is the difference between the price determined by the auction and the price of the wholesale energy. Public auctions for electric energy generation have become the system chosen by policymakers to adjust the issue of energy affordability in Brazil: with a target on the lowest energy price, there is lower impact on the cost of electricity to the final consumer (Camillo, 2013).

In its first round of the ASA, in 2007, 9 alternative projects were authorized, which totalized 939 MW of contracted energy. However, wind energy was only included in an exclusive contracting mechanism in 2009, through a Reserve Energy Auction. In this round, 339 projects were enabled, totaling 10,005 MW, of which 1,805.70 MW of wind energy, distributed in 71 parks, averaging 66.88 USD/MW in current prices.

Beginning with the 2009 Reserve Energy Auction, wind energy was presented in 20 specific auctions between 2009 and 2018, as shown in table 2, which displays the amount added in each round. From this, it can be said that the wind power source was contracted basically by three different mechanisms: Reserve Energy Auction (LER), New Energy Auction (A-3, A-4, A-5 and A-6)⁶, and Alternative Sources Auction (LFA).

The year of 2012 presented great challenges and difficulties for wind energy. In 2012, it is worth noting that only one

⁵ Proposals are classified by cost and the competition is determined in terms of price per MWh. Auctions have the role of defining the tariffs that are paid by concessionaires to producers, which will possess a long-term energy supply contract as well as a guarantee of payment according to a stipulated amount.

⁶ Power plants that begin commercial operation in up to, respectively, three, four, five and six years.

auction was held in December 2012, in the A-5 modality. In MW referred to wind energy sources. the event, only 574.3 MW were contracted, of which 281.9

Table 2: Share of Wind Energy in Auctions – 2009 to 2019

Auction	N° of Contracted Projects	Installed Capacity (MW)	Average Real Price (USD/MWh)
03/2009 (LER)	71	1,805.70	66.88
05/2010 (LER)	20	528.20	52.33
07/2010 (LFA)	50	1,519.60	56.29
02/2011 (A-3)	44	1,067.60	40.40
03/2011 (LER)	34	861.10	40.15
07/2011 (A-5)	39	975.70	41.77
06/2012 (A-5)	10	281.90	33.34
05/2013 (LER)	66	1,505.20	39.41
09/2013 (A-3)	39	867.60	43.91
10/2013 (A-5)	97	2,337.80	41.76
03/2014 (A-3)	21	551.00	44.02
06/2014 (A-5)	36	925.55	45.31
08/2014 (LER)	31	769.10	47.37
02/2015 (LFA)	3	90.00	56.30
04/2015 (A-3)	19	538.80	56.31
09/2015 (LER)	20	548.20	61.49
04/2017 (A-4)	2	64.00	29.52
05/2017 (A-6)	49	1,386.62	26.40
01/2018 (A-4)	4	114.40	18.02
03/2018 (A-6)	48	1,250.70	24.17
03/2019 (A-4)	3	95.2	20.39
04/2019 (A-6)	55	1,570.2	23.80
Total	761	19,654.20	-

Source: Completed with data from ANEEL (2020)

The success of wind power is confirmed by the contraction of 19,654.20 MW in the Regulated Contracting Environment (ACR)⁷, between 2009 and 2020. Such success can be attributed to the competitiveness of this source, which, given its relatively low cost in the auctions, has ensured both an indication of minimum amount to be contracted by the government, as well as its effective contracting. This competitiveness is the result of several factors, such as the quality of the wind resource in certain

regions of the country and the signaling provided by the indicative planning, which imply the maintenance of a perspective of wind energy expansion.

Figure 7 gives the average real prices per source for the auctions conducted between 2005 and 2019. From this, it can be said that wind energy had an excellent performance. Regarding the average data observed in the auctions from 2005 to 2018, wind energy ranked as the second most

7 The commercialization of energy in Brazil is carried out in two market spheres: The Regulated Contracting Environment (ARC) and the Free Contracting Environment (ACL). Basically, the

differences between them are the restrictions imposed between the markets. The ACR follows a series of regulatory criteria that are not included in the ACL.

competitive, behind only the hydroelectric plants. In the case of the hydroelectric source, this advantage can be attributed to their technical-economic characteristics, such as the size of the enterprises, which allows economies of

scale, as well as the cost structure, which includes marginal production costs close to zero. However, with the growth in the number of wind farms, and with the advancement of technology, that gap is likely to decrease or even reverse.

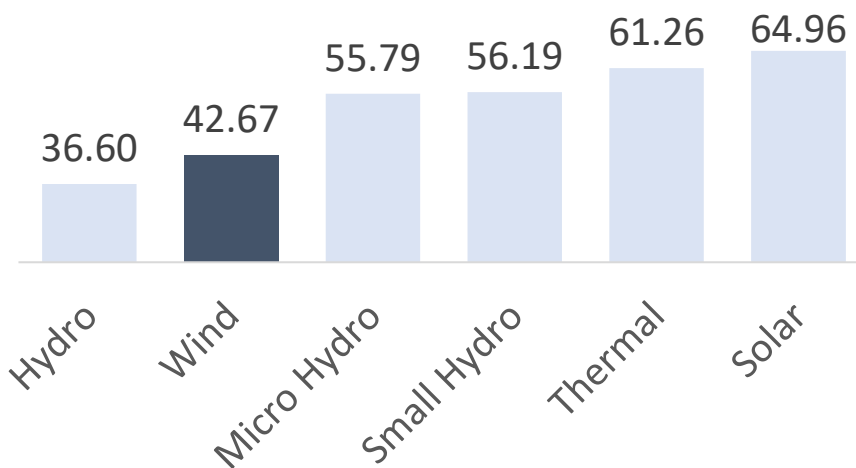


Fig.7: Average Prices⁸ by Source for the Energy Auctions from 2005 to 2019 in USD/MW⁹

Source: Completed with data from ANEEL (2020) and IBGE (2020)

In 2019, the seasonality¹⁰ of contract delivery has been changed for solar and wind energy. In the “A-4” auction, the seasonality of contracts followed the generation profile of the projects, while in “A-6” seasonality was chosen according to the load profile, which allows for a more equitable competition and values developments that best meet consumer requirements. The results of 2019 new energy auctions demonstrated the consolidation of very competitive prices in the regulated marketing environment, especially for wind sources (EPE, 2019b).

The Brazilian Energy Research Company (EPE) is currently studying the possibility of the participation of power plants hybrids and new technologies, such as offshore wind, in future energy auctions. EPE is actively involved discussions regarding these topics. The company notes that it is important to advance in hybrid projects, mainly with wind and solar energy projects that could result in more flexible portfolios and bring benefits to the system. However, regulatory definitions that will contribute to greater clarity of rules and security for entrepreneurs are still needed (EPE, 2019b).

V. CONCLUSIONS

Wind energy has played an increasingly important role in the Brazilian Power Sector. Currently, this source is already positioned as the third in terms of installed capacity in the Brazilian electricity matrix, behind only hydro and thermal sources. In terms of prospects for expansion of wind energy, its importance is even greater. From the plans presented in this paper, it is estimated that the wind power source will reach the second position in 2029, when it will account for 17.32% of the total installed capacity.

The country's wind power generation potential is reinforced by analyzing the capacity factor, which puts Brazil in the leading position in terms of the productivity of this source. This means that not only does the country have high capacity for expansion, but it also has the best performance in wind generation in the world. Furthermore, it should also be pointed wind energy's complementarity characteristic with the country's main energy source: hydroelectric power. When analyzing the seasonal behavior of wind energy, it is observed that it has higher productivity in the dry period of the year, precisely the period in which hydroelectricity presents worse performance.

Regarding the prices that resulted from the generation

8 By order: Hydroelectric Plants (more than 30 MW); Biomass Plants; Wind Power Plants; Small Hydro Plants (1 to 30 MW); Hydro Generating Plants (less than 1 MW); Thermolectric Plants (THER); Solar Plants (SOL).

9 For the conversion, an exchange rate of 3.9453 Reais per Dollar was used, given the Central Bank of Brazil on April 30, 2019.
10 Seasonal adjustment.

auctions of the last years, it can be concluded that there is extreme competitiveness of wind energy in Brazil, which contributes to a lower cost of generation in general. The country introduced some investment coordination mechanisms that have allowed the reduction of risks, making wind energy economically viable in Brazil. In addition, PROINFA remains as an important government tool for the promotion of alternative renewable sources in the production of electrical energy.

In this sense, wind energy stands out in the Brazilian scenario for its contribution to the country's power generation capacity.

Wind energy also stands out for being a type of energy that can minimize environmental impacts caused by the installation and operation of its plants, as well as providing great conditions for the country's sustainable and socioeconomic development, job generation and income, expansion of residential electrical supply through energy renewable, reduction of CO₂ emissions in electricity generation and eventual collaboration and reduction costs in reaching energy demand in times of a hydroelectric crisis.

In summary, the recent development of the wind energy industry in Brazil is explained by important structural factors, with an emphasis on technological progress and wind characteristics, in addition to attractive financing and contracting conditions at auctions.

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