Integrating Wind Power to the National Interconnected System in Brazil

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***Abstract*—The goal of this study is to characterize wind resources as a source of energy. In particular, we characterize their supply and demand on the Brazilian energy grid through the methodological tools offered by Integrated Energy Resources Planning. The study develops two energy scenarios for wind power. First, we develop a business as usual, which ponders social, economic, environmental and political aspects. Second, we develop a sustainability scenario, which evaluates the potential of wind power as a renewable resource, and its potential as an alternative to reach a sustainable development that reduces CO_2 emissions. To develop both scenarios, we use estimates of supply and demand for the next 50 years, which reflect the needs and interest of those involved on the issue.**

***Index Terms*—wind power, sustainable scenario, integrated resource planning**

I. Introduction

This study addresses the most relevant elements to wind power supply, which we use to build tendency and sustainability scenarios for both supply and demand of power for the period from 2014 to 2062. This study analyzes data of historical consumption by type of service from the *Energy Research Company* EPE, and data of population growth from the *Instituto Brasilero de Geografia y Estadistica IBGE*. We project the growth tendency of wind power supply with data from current markets, and growth projections included in the National Energy Plan, 2007 [1].

This study highlights the importance of political factors to make a decision about available alternatives [2]. This requires taking into account interested actors, which should encourage governments to design better public policies and to promote the use of wind resources. Accordingly, we analyze incentives that deal with renewable sources such as quota systems, auctions, price systems, and subsidies. These mechanisms contribute to open markets to renewable sources, thus making real the inclusion of wind resources to the energy grid in a context where sustainable development is a goal.

We present wind power as an interesting option for the upcoming decades. It requires new energy policies and incentives. In addition, new technologies should contribute to optimize wind resources, reduce technical loses, and improve energy storage. It is expected that technological innovations will make significant contributions to achieve energy efficiency, and to increase the capacity of the generation equipment that adapts to existing wind conditions in Brazil.

II. Business as Usual

A. Estimated Supply of Wind Power

This study intends to evaluate the most relevant factors in the supply of wind power, which we use to develop tendency and sustainability scenarios for both consumption and supply of power during the period from 2014 to 2062. Regarding the estimated supply of power generated with a wind source, we consider the projected growth of the existing wind potential, and new projects that will begin to operate in the short-term. Several studies indicate that the potential to generate wind power in Brazil is greater than 60.000MW. Nonetheless, this estimate cannot be established with certainty due to the lack of information about the available surface, and because current methodologies have limitations. The Wind Atlas of Brazil [3] estimates that, at an altitude of 50m, the wind potential in Brazil is 143GW, or almost 270TWh/year. This is half of the annual power consumption in the country.

The installed capacity went from 30MW in 2005 to 6.56GW in 2015, which amounts to a growth of more than 100% each year throughout this period. Moreover, it is expected a growth of more than 16GW in the installed capacity for 2021, of which the new wind parks, that will begin to operate in 2021, comprise 21% of the Brazilian energy grid. According to the Decennial Energy Plan, this implies a growth of 9% in the installed capacity for 2021 [4].

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Fig. 1 depicts a considerable increase in the projected installed capacity beginning in 2021 through 2060. This reflects the execution of public policies intended to clean the Brazilian electric grid, and to increase their market share by making prices of these energy sources more competitive. In 2015, Brazil has 262 wind power plants, which amounts to an installed capacity of 6,56GW. This quantity is used to estimate the projected installed capacity. We also use expected decennial growth rates and demographic and economic factors that directly affect the energy source considered in this study.

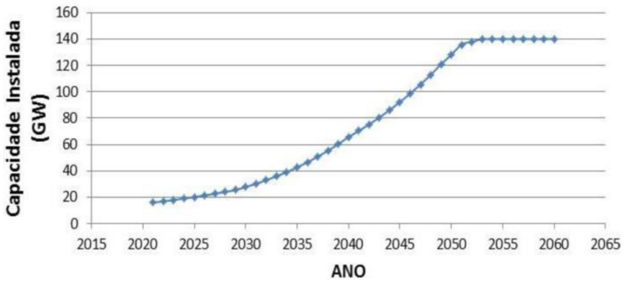

Figure 1. Forescast installed capacity of wind power in Brazil.

Data projections on Fig. 1 depict growth percentages by decade. They incorporate demographic and economic factors that affect directly the energy source studied here. Beginning in 2021, we estimate that, because of the steady growth of wind power installed capacity, it will seize a greater share of the energy supply. Thus, from 2020 to 2030, growth will reach 7% with the operation of new wind parks.

Decade 2030-2040: the growth of the wind industry may reach 9%. The growth of installed capacity results from governmental efforts through public policies, and regulatory and legal incentives. Also during this decade, pré-sal exploration estimates future reserves that would rank Brazil as the sixth petroleum producer in the world, and the largest ethanol producer. These conditions enable it to make large investments on clean energy that prioritize wind sources over biomass' lower performance. Also, technological innovations will allow a more precise measurement of wind, and quality certifications for wind generators will be obtained.

Decade 2040-2050: Economic forecasts depict Brazil as a country with a solid and stable economy. Public policies during this decade will permit to distribute revenue efficiently, which should guarantee a sustained economy. International risk agencies continue to estimate its Country risk with a stable investment degree, which continues to attract investments on infrastructure projects in Brazil.

Decade 2050-2060, growing at a 7% by the end of the decade, Brazil will reach its full wind potential at 144 GW in installed capacity, thereafter keeping its installed capacity of wind power. According to data analyzed about the development of wind resources, it will reach its full potential in 2050, and it will keep a stable generation capacity.

If we keep in mind that installed capacity in Brazil is going to grow four times by 2050, and that installed capacity in 2014 is 139GW, it can be inferred that by 2050 we get around 496GW installed, among which wind power will comprise approximately 29%. Table I depicts the proportion of the energy demand that is supplied by wind power between 2020 and 2060.

TABLE I. ENERGY SUPPLY BY WIND POWER

Year	Installed Capacity of Wind GW	Installed Capacity of Wind GWh	Total Energy Consumption GWh	% of Demand Served by Wind power
2021	16	140.160,0	632.630	22%
2030	29,4	257.544,0	973.093	26%
2040	69,6	609.696,0	1.496.785	41%
2050	137	1.200.120,0	2.302.313	52%
2060	144	1.261.440,0	3.541.355	36%

B. Economic and Technological Aspects of Wind Resources

Existent technologies: Technology makes a significant contribution to incentivize the expansion of wind power generation capacity. Technology development can take place through advanced transmission systems, better aerodynamics, and optimized methodologies to operate turbines that exploit efficiently this resource, and improves its reliability. Additionally, power control of turbines, which determines that the maximum power generated, can be enhanced using technology. In sum, nominal power reaches 4,5MW during the next years [5].

Technological progress is fundamental to incentivize wind power expansion. Although estimates of wind potential in Brazil reach 60000 MW (Annel), technological innovations can increase this quantity. Technological progress may take place in advanced transmission systems, better aerodynamics, and optimized methodologies to manage turbines that improves how this resource is exploited.

ANEEL's nomenclature classifies power potential as:

1) Small - nominal potential lower or equal than 500kW, which are used in small communities, ranches, and remote applications.
2) Medium – Nominal potential ranging from 500 to 1000kW, which are allocated to small communities, hybrid systems, and distributed generation.
3) Large – Nominal potential greater than 1MW, which is allocated to be used in wind parks, and distributed generation.

C. Financial Viability of Wind Power Projects

Wind power attracts large investments, both national and foreign. Since 2009, 17 companies that produce wind generators have arrived to Brazil. The country invests heavily in wind parks due to the need to increase its market share, and to expand their demand. Nowadays, 40% of the equipment used to generate wind power is imported. It is estimated that Brazil is the country that invests more heavily in wind power. Given existing policies and incentives, it is anticipated that this equipment will be fully assembled in Brazil in the next decade.

In addition, investments on energy are privileged because the factor capacity of wind projects may reach 50%, which ranks Brazil above countries like Germany, and the United Kingdom, where the capacity factor is not greater than 25%. It is apparent that factor capacity in Brazil ranges between 27% and 54% [5]. As a result of investments on technological innovation, it is possible that wind turbines or air-generators will be assembled locally by 2030.

Job creation: Wind industry creates more than twelve thousand jobs in the production of wind generators, and twenty thousand direct jobs will be created to build wind parks until 2016, most of which are local workers. During this period, 280.179 direct and indirect jobs will be added until 2021, according to Abeeeólica. Most of them related to the construction of wind parks. Moreover, there will be approximately 6.230 permanent jobs to operate and upkeep these facilities.

III. Political Aspects of the Analysis

Political factors do not follow any established model, which implies that it is a permanent source of uncertainty in the planning process. Nonetheless, it has to be assessed given its importance in the process displayed on Fig. 2. It is methodologically difficult to make a quantitative assessment of them [2]. However, we can still consider the interests of the various political agents.

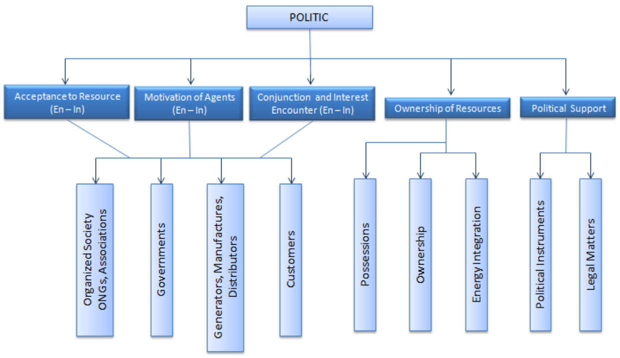

Figure 2. Attributes and sub attributes of the political dimension: [6].

Historic data is the obvious reference to build scenarios, but the uncertainty associated with political aspects makes necessary to introduce a resource efficiency perspective that keeps in mind the nature of the energy resource at hand. It is clear that those making policy decisions ought to assess the benefits of using wind power as a renewable resource within the Brazilian energy grid.

A. Extent to Which the Resource Is Accepted

Wind power is accepted to the extent that investors perceive adequate returns, and prices are defined in a favorable context of free acquisition. For the society as a whole, mainly as consumers, this resource acceptability depends on whether there are competitive fees to the final consumer.

Differential fees are a guiding principle within the school of public services that should be interpreted as conditioned by the efficiency of service providers [7]. To the extent that resources used to provide a service are projected efficiently, there will be greater returns for the agent. Public policies are needed in this area too, to incorporate crossed subsidies across various types of consumers.

Finally, we consider that a motivation for those interested in the supply side of power is to secure guiding principles of public services provision, such as uninterrupted service, low fees, and universalization. Respect and assurance of these principles allow to enhance the well-being of those interested. This justifies that governments remain vigilant to secure these principles, and to facilitate market competition.

B. Motivations of Agents

The main motivation of Governments to implement wind projects is to clean the energy grid, while they also increase alternatives to supply power. This requires to coordinate investors' interests that intend to invest in the sector and the interests of society at large. The preference of those interested is to have a clear energy policy that accommodates their interests, and the resources available. At the present time, wind resources attracts national and foreign investors, which facilitates the growth in the number of initiatives to develop wind plants, and to enlarge markets through auctions.

Regarding the motivations of the society in general, there are two fundamental factors. First, they want to have employment opportunities. Second, they expect to have lower fees as a result of the varied supply of power, and because thermal plants would not be needed when hydroelectric supply faces restrictions.

Residential consumers' motivations to acquire wind power depend on the existence of fiscal incentives for small and medium wind projects that benefit final consumers. They also depend on the existence of an energy regulation that incorporates the possibility to export excess power to the national system.

C. Conjunction of Interests

Those involved and interested must be identified to develop projects of clean energy that put forward a shared structure of public policies that include political groups, and that value their interests. Society, and governments at the federal, state, and municipal levels, have the common interest to obtain energy resources, and to manage them adequately.

When natural and energy resources are classified as liable objects of public interest, even though this concept may seem abstract at first, it constitutes the origin of its judicial existence. Thereafter, it can be protected in every public administration scenario, the judicial power, and through existing legislation.

D. Property of the Resource

As a result of agreements between public and private agents new infrastructure projects will be developed, in which interests and needs of public and private sectors coverage through judicial instruments that facilitate to develop projects with private resources for the public sector. Using this normative instrument, private investors are compensated directly by the government or through the combination of fees being collected, and resources coming from the public sector; according to Law 11.029 of 2009.

At the same time, it is also possible to develop wind power projects through the normative framework offered by concession contracts (Law 8.987 of 1995). This kind of administrative contracts establish that resources used to provide public services are to be considered public goods. Consequently, they revert to the public sector at the end of the concession. With this purpose, paragraph 1 of article 35 in Law 8.987 of 1995 establishes that, once a concession is over all revertible goods, rights, and privileges, return to the power ceding them according to what contracts and the public notice state.

E. Estimated Demand

Estimated growth of power consumption is 6GW per year, according to the company "*Empresa de Pesquisa Energ ética"* EPE. These estimates are used to project the demand of power to 50 years, which takes into considerations population growth and estimates of historic consumption growth calculated by the EPE for each type of service during the last ten years.

F. Population Growth

According to information gathered by IBGE for the period 1950-1960, population growth decreased from 3,04% by year to 1,05% in 2008. For 2050, they establish that growth rate will plummet to -0,291%. This amounts to a population of 215,3 million inhabitants in Brazil. Keeping this rate, it is estimated that by 2060 population in Brazil will be close to 221 million of inhabitants; this is illustrated on Fig. 3.

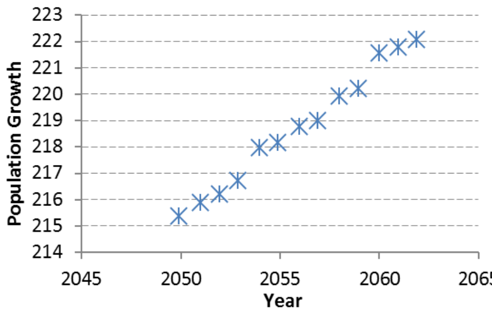

Figure 3. Population growth. Source: based on IBGE (2015).

Additionally, yearly growth experienced by the country gets reflected on energy consumption. This includes an increase in the places where consumption takes places, but also higher individual consumption [2].

G. Power Consumption by Type of Service

Power demand in the scenario takes into account historic consumption data between 1995 and 2015, and the rate of growth throughout these years calculated by the "*Empresa de Pesquisa Energ ética"* EPE for each type of service.

Based on data from the EPE about consumption by type of service during the last 10 years, we estimate the growth rate for the next 50 years starting with a 4,9% for the residential class, 3,6% for industrial, 5,8% for commercial, and others with 4,4%. This leads to a consumption growth from 448,276GWh in 2012 to 3541,354GWh in 2060, which is displayed on Fig. 4.

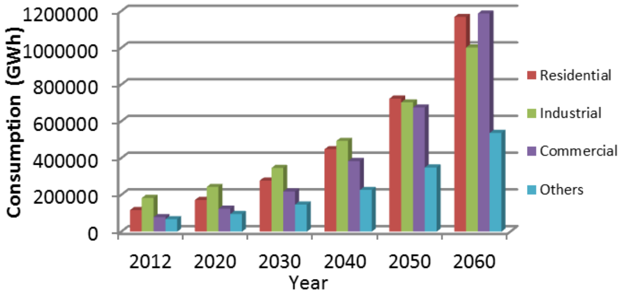

Figure 4. Projected consumption by type of service, 2012-2060

On the other hand, we also take into consideration that internal consumption decreases during the next decade because the Tax on Industrial Products is abolished for residential products, and it was reduced for goods such as automobiles.

IV. SUSTAINABILITY SCENARIO

Using data on the supply and demand of wind power, we try to project a sustainable evolution for this resource in the energy grid, and for the long term. Particularly, we intend to illustrate the exploitation of energy resources and their impact, when efficiency improves, on the final user and on the use of various energy sources.

Wind power is considered a clean and sustainable energy resource with the highest growth in the medium and long term. This growth needs to articulate demand and supply to achieve a sustainable development.

Wind power source, as renewable energy, could become the second source of energy, thus promoting a clean development for Brazil. Granted that Brazil continues to reach economic maturity, it is viable to implement turbines for wind power generation that benefit end consumers in the various types of service. This includes residential (buildings, houses, rural areas) with competitive prices, and easy access that facilitates a secure investment. This should result in a reduction of global warming as suggested by the sustainable economic model [8].

Since about 85% of power in the country comes from hydroelectric sources, Brazil is exposed to its natural seasonality, which reduces the overall reliability of the system. Consequently, it is important to consider complimentary energy sources, especially if they are renewable. This is critical given the deficit faced by hydroelectric reservoirs, which forces the country to activate its thermal plants, exactly as it occurred during 2004. New renewable sources are gaining ground within the energy grid over hydroelectric energy, which increases the diversity of sources across the electric Brazilian system.

Following the chart about political factors, we will incorporate to the sustainability scenario political and legal instruments available for the wind source to continue growing within the energy grid, which would further contribute to clean it and diversify its sources.

The sustainability scenario analyzes the relationship between increases of wind power supply presented on Fig. 2, and the expected reduction of CO_2 emissions. As a result of contracts agreed through wind power auctions in 2014, 1,2 million tons of CO_2 were avoided each year. In 2015, 7,2 million tons of CO_2 will be avoided, and 13,2 million tons in 2021. We can conclude that these are effects of articulating legal and political instruments that focus on increasing opportunities for wind power. In consequence, Table II shows the relationship by decade between enlarged installed capacity, and declining CO_2 emissions.

A. Legal Instruments

Among the political factors, legal rules are an instrument that contributes to structure the institutional framework to make the transformations needed in the energy sector to be more sustainable and to make a reality the reductions of CO_2 emissions projected in Table II.

TABLE II. SHARED WIND POWER OF TOTAL ENERGY CONSUMPTION

Year	GW	Emission Reduction Ton (CO_2) per year
2021	16	13.700.000
2030	17	25.186.891
2040	19	59.626.531
2050	142	121.587.500
2060	144	123.300.000

Decade 2020-2030: One of the judicial instruments is the process of auctions with the participation of renewable sources. They result in contracts to trade energy. Legal instruments regulating this process are: Laws 10.848 of 2004, Law 11.488 of 2007, Decree 5.163 of 2004, Decree 6.353 of 2008, Ministry of Mining and Energy decision 178 of 28 of 2013, 132 of 25 of 2013, 29 of 28 of 2011, and Normative Resolution 337 of 2008.

Decade 2030-2040: During this decade, legal instruments will continue to favor the expansion of energy coming from wind power through auctions that result in long-term contracts, which leads to increase by 9% the participation of wind power within the energy grid. Long and medium term contracts established through auctions will enjoy enough normative stability with the support of mature legal and regulatory foundations. New legislation will streamline the process to obtain documents need to develop projects, like Documents of Project (DCP).

During this decade, new norms introduce successfully the Feed-in-Tariffs incentive. This is the instrument that boosts more effectively the incorporation of renewable energies. Similarly, wind power gets its own fees model that includes applicable subsidies, and the period during which they will be in effect. These mechanisms should promote investors' economic equilibrium [8]. Tax exceptions on the Movement of Merchandize and Services and the tax on Industrial Products will remain effective. End consumers' freedom to choose their source of energy will be fulfilled.

Decade 2040-2050: Auctions of contracts to trade power in a regulated market continues. Nonetheless, during the decade the system becomes more mature, and auction processes for wind power sources are programmed more rigorously. During this decade, norms, and energy public policies make possible to anticipate the amount of wind power that will be bought in the market, which strengthens markets for both supply and demand. In this decade, feed-in-tariffs are applied to preserve a market specific to wind power. Also, a policy of freedom to choose their source of energy and to choose its provider consolidates. The country reaches 100% of the necessary equipment to generate wind power.

Decade 2050-2060: Contracts to sell energy as a result of auctions continue. Incentives like feed-in-tariffs begin to decrease. Additionally, legislation incorporates incentives through a quota system for every renewable energy. The national government will set the amount of renewable energy that will be generated given the fact that at the beginning of the decade Brazil will reach its maximum wind capability. Quota incentives are known in the literature as Renewable Portfolio Standard (RPS) o Renewable Energy Targets. When green power goals are set, investors can derive profits, and bargaining procedures get established with green certificates [9].

V. CONCLUSIONS

The obvious consequence of incorporating wind power to the Brazilian power grid, and its gradual growth, is that emissions decrease due to the lower use of other non-renewable energy sources such as thermal plants. Thus, we have determined that by 2021, a possible reduction of CO_2 emissions will be 13,7 million tons, which reflects an installed capacity of 16GW. Based on this, we projected in the business as usual that supply of wind power in 2060 would reach full wind power potential for Brazil, that is, 144GW. Accordingly, yearly CO_2 emissions will be reduced at 123 million tons.

It is relevant to consider that even if wind power becomes the second source of power in the Brazilian electric grid, its availability is not constant throughout the year. That makes it complimentary to other sources of energy; particularly, hydroelectric power, which experience seasonal and weather shifts.

Besides the environmental benefits of wind power generation, it reduces costs to the energy sector as it prevents the use of thermal plants to satisfy the demand when hydroelectric plants faces the dry season. According to ABEEólica (Brazilian wind energy Association), in 2014, approximately R$1,6 billion were spent on thermal energy. A fraction of these savings could be used to take care of other needs in the electric sector. For example, it could help to move forward universalization plans, and it could help to reduce the importation of power between subsystems.

Public policies during the next few years could include technological enhancements that take into consideration Brazilian particularities. It is expected that in 10 years Brazil will have its own industry to satisfy the demand for the equipment to generate wind power. In addition, public policies favor investments in wind power investments. There are exemptions to the tax on the Mobilization of Merchandize and Services, and the tax on Industrial Products, which makes more attractive to invest in this sector.

Finally, to the extent that public policies articulate normative and economic aspects, social outcomes will have a greater impact that further advances the social goals of the State. There is no doubt that the law, as an instrument to advance social goals, is permanently put to test, which lead to results that benefit society, and increases their well-being.

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