Exploratory Study about Wind-Solar Hybrid Power Plants in Brazil

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ABSTRACT

The Brazilian Electric Matrix needs energy sources diversification and installed capacity expansion to preserve national energy security and maintain or increase its renewable predominance. In this context, this work aimed to carry out an exploratory study on the combined centralized generation via wind-solar hybrid power plants in Brazil to view its respective current panorama and perspectives. The methodology used was information search through bibliographic research of national technical documents and academic articles. The results verify that there is still no specific regulation of wind-solar hybrid power plants in Brazil, but indicate that there is potential for implementing this type of enterprise, especially in the Northeast region. The conclusion is that the use of wind-solar hybrid power plants in Brazil can be a relevant and benefit opportunity for the Brazilian Electric Sector. However, it needs a regulatory advance to fill the vacuum of the current regulatory framework and encourage the implementation of this type of project.

KEYWORDS

Combining Centralized Generation. Wind-Solar Hybrid Power Plants. Regulation. Brazil.

INTRODUCTION

The power generation abundant and sustainable to ensure the present and future evolution and prosperity of populations is a challenge that many countries around the world are seeking to solve. Considering this, the renewable energy development is a key factor for the transition from current global energy and electrical matrices, still based on fossil fuels, to new and diversified matrices based on sources with lower environmental impacts.

Among types of renewable energy, wind and solar sources have stood out significantly in recent years in terms of investments, research and expansion of installed capacity in the world. In many cases, there is an energetic complementarity between wind and solar sources. In this circumstance, the combination of wind and photovoltaic (PV) technologies for centralized electricity generation via hybrid power plants is a possibility. However,

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centralized generation through hybrid power plants is a very recent issue in the world. Thus, studies on this topic are relevant and innovative to help in a more renewable energy future for Brazil and the world and should be realized.

METHODOLOGY

The adopted methods ware an exploratory research of technical documents and academic papers, a general contextualization of wind-solar hybrid power plants in Brazil and respective analysis. The main references of brazilian public administration about energy are: the Ministry of Mines and Energy of Brazil (*Ministério de Minas e Energia* – MME), the Energy Research Company (*Empresa de Pesquisa Energética* – EPE) and the National Electric Energy Agency (*Agência Nacional de Energia Elétrica* – ANEEL). MME is Federal government institution responsible to define the basic principles and directions about the national energy police. In addition, MME promote many studies and analyses about the sector energetic planning. EPE is a public company linked with the MME and created in 2004. Their aim is make studies and analyses in energy sector to support the sector energetic planning for example: Energy National Plans (*Planos Nacionais de Energia* – PNE), Energy Expansion Decennial Plan (*Planos Decenais de Expansão de Energia* – PDE), National Energy Balances (*Balanços Eenergéticos Nacionais* – BEN), technical notes and others documents. ANEEL is the public agency that makes the regulation and supervision about activities of generation, transmission and distribution of Brazilian electricity sector.

The hypotheses presented are: (i) The existence of a great energy potential to be explored by combining centralized generation in Brazil, (ii) There is no specific regulation to combining centralized generation, however this question was be officially discounted from 2017, (iii) Already there are wind-solar hybrid power plants and futures pilot-projects plans in Brazil; (iv) The hybrid power plants are a new opportunity for Brazil expand and optimize your electricity matrix.

WIND AND SOLAR ENERGY CONTEXTUALIZATION

Global energy consumption is increasing due to population growth and increasing industrialization (Bahramara *et al*., 2016). Santos (2015), also mentions as factors that directly influence electricity demand and natural resources: economic growth, the increase in the average income of the population, consumption patterns, urbanization and the price of energy. Thus, to meet the growing energy need, humanity has resorted to various sources of supply: non-renewable (oil, natural gas, mineral coal, etc.), which are finite and renewable (hydraulic, wind, solar, biomass energy, etc.), which are considered inexhaustible.

Toklu (2013) stated that there will be a growth trend for renewable energy until 2100 to meet the growing world demand for global energy. Sooriyaarachchi *et al.* (2015) and Santos (2015) commented that issues related to climate change and energy security reinforce the importance of inserting and expanding renewable energy in government planning in relation to the energy and electric matrices of various countries. In addition, various issues related to environmental preservation, legislation advances, job and income creation, public opinion and sustainability in general have been acting in favour of expanding the use of renewable energy sources.

In 2015, during the 21st Conference of the Parties (COP 21) of United Nations Framework Convention on Climate Change (UNFCCC) in France, the international community signed the Paris Agreement, which is also intended to continue efforts to limit the temperature rise to

1.5°C. This signalled the beginning of a new era of global geopolitics geared towards a low-carbon economy, in which an energy transition towards renewable energies would be inevitable. Some reports by the Intergovernmental Panel on Climate Change – IPCC (2014a, 2014b, 2018, 2019) of the United Nations (UN) confirmed the urgency in adopting actions against Greenhouse gases (GHG) emissions, as, otherwise, the capacity to adapt and The resilience of the environment may not be enough to rebalance itself, thus posing risks to life on planet Earth. The International Energy Agency – IEA (2020) emphasized that, to avoid the worst consequences of climate change, the global energy system must rapidly reduce its GHG emissions and investments in renewable energy will be indispensable, where wind and solar energy will play key roles. Thus, the growth trend of renewable energy should be more intense and faster than the estimates made by Toklu (2013).

Global Overview about Wind and Solar Power Potentials

The World Bank (2019a, 2019b; 2019c) and partner entities (ESMAP, 2020) have recently prepared studies on global wind and solar PV potentials (Figures 01 and 02) to guide countries and companies interested in expanding these energy sources.

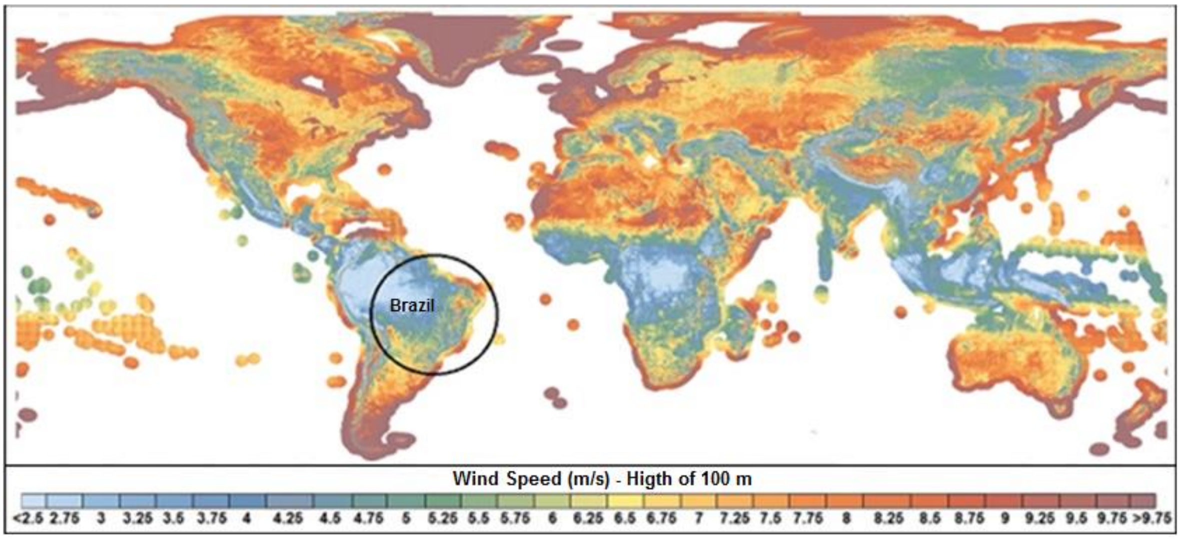


Figure 01. Global Wind Potential (onshore and offshore) at 100m. Sorce: WORLD BANK (2019a). Adapted.

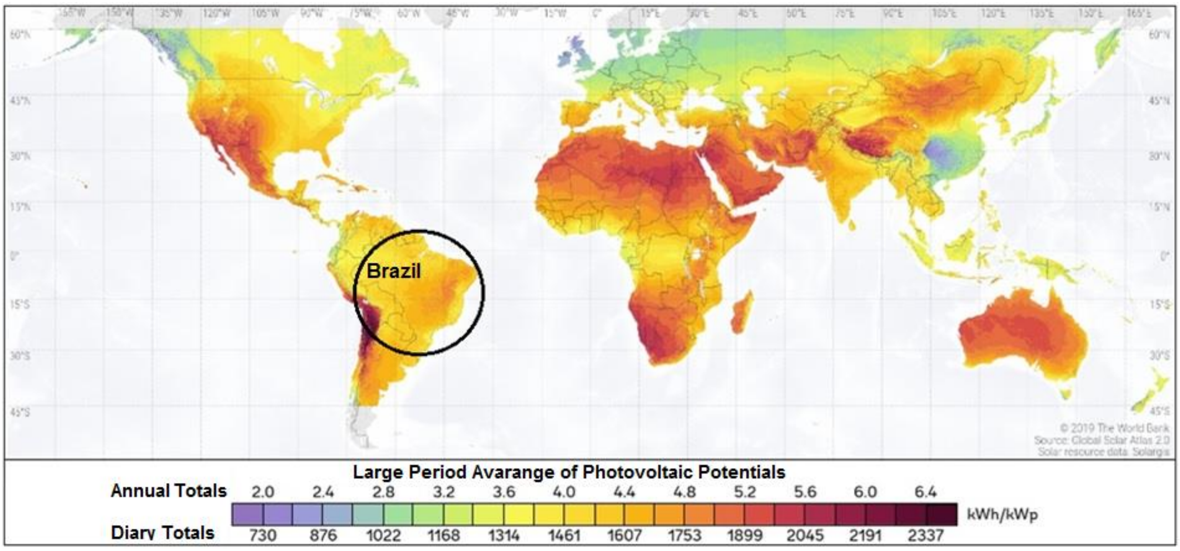


Figure 02. Global Solar PV Potential for power generation. Source: WORLD BANK (2019b). Adapted.

Hart *et al.* (2012) say that renewable sources have shown a significant potential for reducing CO_2 emissions associated with the electricity sector, but that the intermittence of these resources is often cited as a barrier to their large-scale integration into the electricity grid. However, if renewable sources are compared to traditional energy sources (based on fossil fuels), they offer the possibility of solving issues of climate change and economic decarbonization, which are currently so relevant. Therefore, analyses and evaluations of renewable energy technologies have received increasing attention in different countries' policy and scientific literature.

Brazilian Power Potentials of Wind-Solar Combined Centralized Generation

Nascimento (2017) reported that the values of global solar irradiation incident in any region of the Brazilian territory (1,500–2,500 Wh/m) are higher than the values of most European countries (Ex.: Germany: 900–1250 Wh/m²; France : 900–1650 Wh/m²; Spain: 1200–1850 Wh/m²), places where solar developments are well disseminated. De Pierro (2017) commented that there is an area in Brazil called the "solar belt", which covers a significant portion of the Northeast, Midwest, Southeast and the state of Tocantins and which concentrates the higher levels of solar radiation. According to Feitosa *et al.* (2003) and CEPEL (2017) several states in the Northeast region have wind resources with speeds above 7 m/s, which makes them attractive for wind projects. Studies by SWERA (2007) and EPE (EPE, 2012; Konzen, 2016) indicate that the high radiation potential found in Brazil is capable of enabling high productivity for solar energy. Observing Figure 03, the geographic coincidence of potentials to power generation of wind (Figure 03-A) and solar PV (Figure 03-B) energy in the Northeast is noticeable. Studies by the Electric Energy Research Center – CEPEL (2001; 2017) and the National Institute of Science and Technology for Climate Change – INCT-Clima (Pereira, 2016) show that Brazil has significant wind potential. The Atlas of Brazilian Wind Potential (CEPEL, 2001) estimated a gross potential of 143.5 GW for a height of 50 m. According to Pereira (2016), the INCT–Clima estimated for a height of 100.m a gross wind potential of up to 880.5 GW, with 522 GW technically feasible. EPE (Tolmasquim, 2016; Konzen, 2016) carried out a technical study on the Brazilian solar potential, considering environmental restrictions among others, and the largest range of solar radiation (6,000 to 6,200 $Wh/m^2{*}day$) has a solar PV potential for CG of 307 GWp in *anthropogenic* areas (already used for human activities) with more than 90% of this potential in the Northeast Region. According to EPE (2017), Santos *et al.* (2020a, 2020b) and Lima (2016a), the geographic coincidence locations in the Northeast are areas with potential for the implementation of wind-solar PV hybrid power plants. However, it to make the implantation of hybrid projects viable, it is necessary, but not enough, the existence of significant energy potentials, because it is also necessary to have an energy complementarity between the sources involved. Lima (2016a) simulated the superposition of the solar-wind complementarity, making a mathematical junction of the units of solar radiation ($kW{*}m^{-2}$) and wind speed (h = m/s => $h^{-1} = (m/s)^{-1}$) (Figure 04). The complementarity of incident solar radiation and wind speed expressed in "$kW{*}m^{-2}{*}h^{-1}$" is shown in Figure 04–A, in which common favorable areas of solar radiation and wind speed are shown. More convenient areas are pointed out for combined wind-solar PV generation. The ideal circumstances of the range of solar-wind variation are found in the range of 1,250 to 1,350 $kW{*}m^{-2}{*}h^{-1}$, where the best conditions of wind speed linked to incident solar radiation are found. This strip comprises an extensive area from Ceará to Bahia. Figure 04–B shows the solar-wind complementarity overlap deviations in the Northeast region. These areas are favourable to implantation of hybrid power plants.

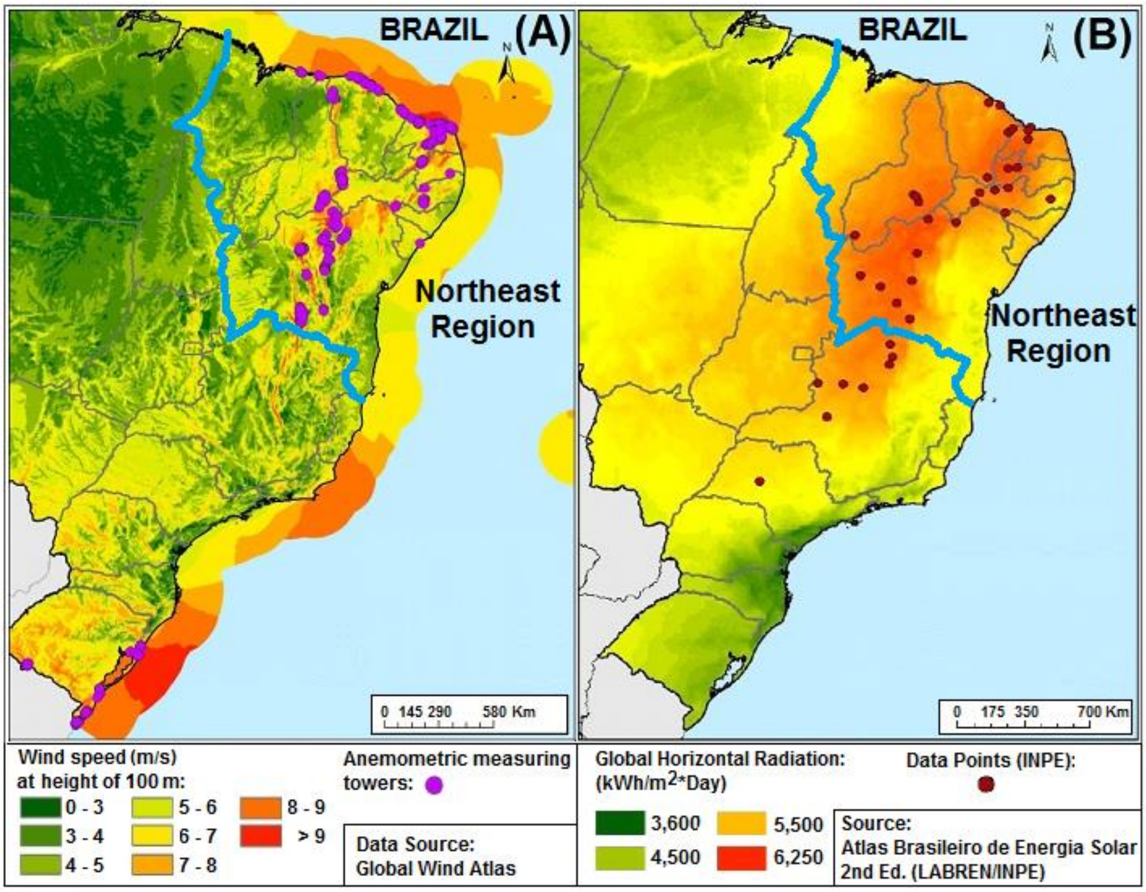


Figure 03. Wind and Solar Potentials in Brazil and measurement stations. Source: EPE (2021b). Adapted.

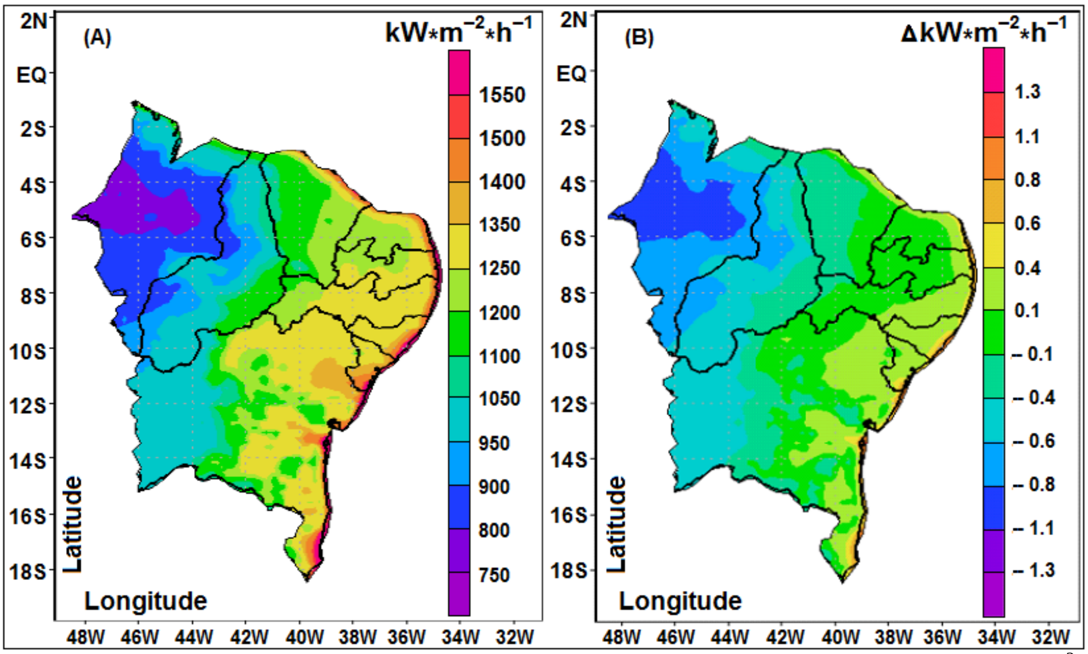


Figure 04. Superposition of: (A) Complementarities of incident solar radiation with wind speed (kW$_*$m^{-2}$_*$h^{-1}); (B) Complementarity overlap deviations (ΔkW$_*$m^{-2}$_*$h^{-1}). Source: LIMA (2016a). Adapted.

Overview about Global and Brazilian Expansion of Renewable Energy Installed Capacity

According to IRENA (2017), Paiva *et al.* (2017) and the IEA (2014) as a result of the expansion of renewable energies, a large-scale market was created that has been making possible investments in systematic technological advances and the cheapening of these new technologies, making these energies gradually more attractive. IRENA (2021a) informs, in 2020, the Levelled Costs of Electricity (LCOE) for power generation projects with renewable energies are competitive or even cheaper than fossil fuel costs, even in the absence of financial incentives (Figure 05). It is possible to observe that the LCOE of onshore and offshore wind energy were reduced and that the LCOE solar PV energy suffered a drastic reduction, which made these energies quite competitive in relation to fossil energies in the last decade. These facts have made wind and PV energy the fastest expanding renewable energy options in the world today. According to information from REN21 (2020), China, the United States of America (USA), Japan, Germany and India were the countries with the largest solar PV installed capacity in 2019. IRENA (2021b) presented the evolution of installed capacities (Figure 04) of renewable energies in the World and in Brazil from 2011 to 2020. It was possible seen that the main renewable sources in the World in 2020 were: hydroelectric, wind, solar PV and bioenergy. In Brazil, it was observed that the main renewable sources in 2020 were: hydroelectric, wind, bioenergy and solar PV. This consistent and prolonged expansion of installed capacities for wind and solar PV indicates that investments have been made continuously in the last decade, despite the global economic crisis of 2008 and the recent slowdown in some of the main world economies, such as China, USA and Europe.

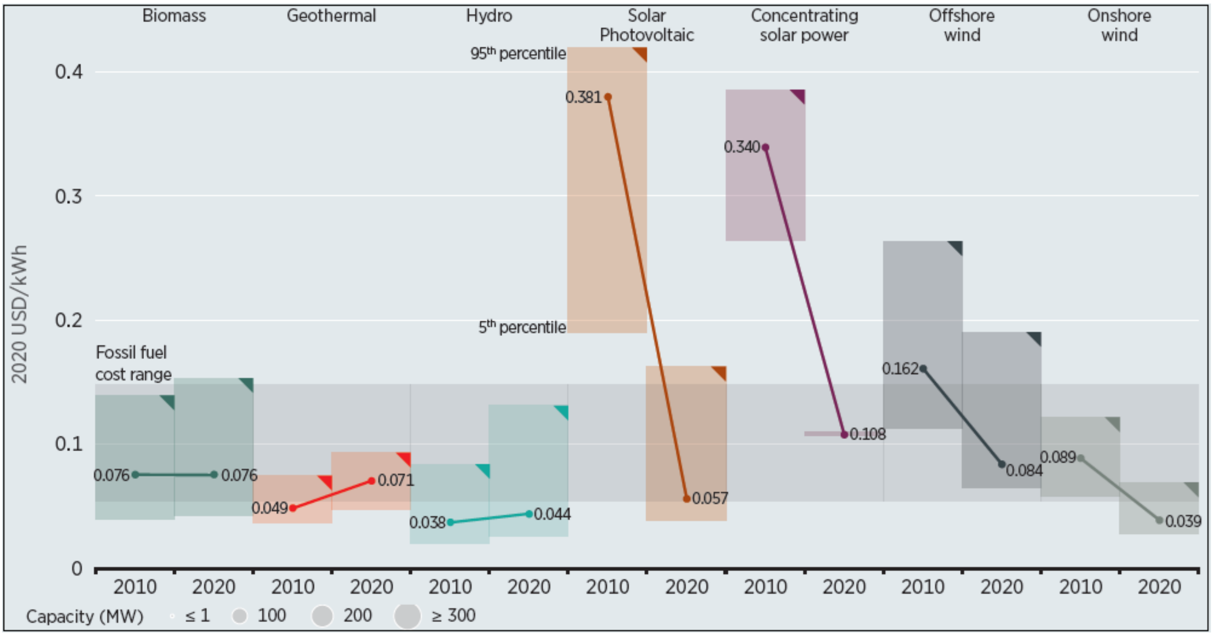


Figure 05. Global LCOEs from newly commissioned, utility-scale renewable power generation technologies: 2010-2020. Source: IRENA (2021a).

In 2020, according to IRENA (2021b), renewable generating capacity expanded by far more than in recent years, well above the long term trend. Most of the expansion occurred in China and, to a lesser extent, the USA. Most other countries continued to increase renewable capacity at a similar rate to previous years. At the end of 2020, global renewable generation capacity amounted to 2.799 GW. Renewable generation capacity increased by 260 GW (+10.3%) in 2020. Solar energy continued to lead capacity expansion, with an increase of 127 GW (+22%), followed closely by wind energy with 111 GW (+18%). Hydropower capacity increased by 20 GW (+2%) and bioenergy by 2 GW (+2%). Geothermal energy increased by 164 MW. Solar and wind energy continued to dominate renewable capacity expansion, jointly accounting for 91% of all net renewable additions in 2020. In Brazilian case, despite of international economic crisis of 2008 and national economic crisis from 2014 until this moment, the installed capacity of wind and solar power continues to grow up.

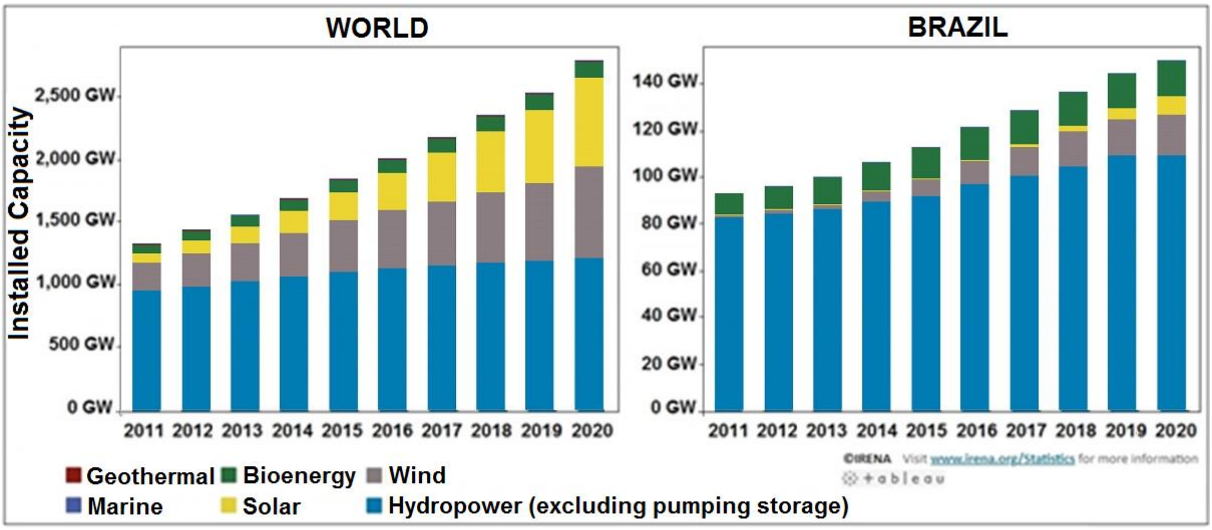


Figure 06. Installed capacity renewable energy evolution in the World and in Brazil 2011-2020.
Source: IRENA (2021b).

According to information of Rodrigues (2021a, 2021b), currently some Brazilian Electricity Sector (BES) players are studying the possibility of hybridization of projects between 1 GW and 2 GW, but the total potential could exceed 20 GW. According to Cunha and Teles (2020), the technical notes of EPE indicated several benefits in the hybridization of energy sources: (i) Greater use of the available capacity of the transmission system; (ii) reduction of system usage costs; (iii) optimization of land use, with the reduction of costs associated with the purchase or lease of the area; (iv) gains in logistics and planning for the implementation of the plants, reduction of operating and maintenance costs, which can be shared between the two or more plants; (v) sharing of the restricted interest transmission system; (vi) unification of environmental licenses and reduction in the cost of financial guarantees.

The most commons problems of the wind and solar PV systems are your dependence on climate conditions (stochastic), and they present intermittence (Mahesh e Sandhu, 2015; Engeland et al., 2017; Moriarty e Honnery, 2007). Solar irradiation and wind speed temporal dynamics are characterized by high natural temporal variability at time scales ranging from minutes/hours to seasons/years because of the dependence on weather and climate conditions (García-Bustamante et al., 2013; Vega-Sánchez et al., 2017). However, they exhibit different variability characteristics (Coker et al., 2013; Bett and Thornton, 2016). There are complementarities for wind and solar sources and there are three types: i) daily, ii) seasonal (or intra-annual), and iii) inter-annual (Cunha and Teles, 2020; Pinto et al., 2018; Pinto, 2016; Pinto, 2017). The union these two sources in a same power plant could reduce the problem of variability and intermittence (Antunes, 2020; Liu et al., 2020; Vega-Sánchez et al., 2017). The energy complementarity and your adequate use can optimize the power production and reduce the need of storage systems and curtailment (Miglietta et al., 2017). The combining use these two technologies can have an optimal performance with complement of power generation by PV systems in during the day and by wind turbines at night (Antunes, 2020). The solar PV use together wind energy, results in a power production more regular and uniform, considering the nominal capacity installed of wind power plants, with addition of solar PV energy could grow up the electricity production around 20%/year (Studzinski et al., 2017)..

INTERNATIONAL EXPERIENCE WITH WIND-SOLAR HYBRID POWER PLANT

In 2017, the Bloomberg New Energy Finance – BNEF (Frankfurt School, 2017) estimated the deployment of around 20 hybrid power plants projects of renewable energy worldwide, each with 10 MW or more of installed capacity. It also informed that there are other projects with a total capacity of 5,600 MW (with more than half of this capacity already installed or planned) and that the trend is for this number to grow significantly in the coming years. According to ANEEL (2020a) and EPE (2019a), there are experiences with hybrid power plants in: India, United States of America (USA), United Kingdom (UK), China and Australia.

India

India is the country that shows the greatest interest in the hybrid power plants development, specifically wind-PV, and has been evaluating this issue for some years. The country has set the goal of reaching 175 GW of renewable energy in 2022, of which about 100 GW PV and 60 GW wind. India too aims that the hybrid power generation strategy was put forward mainly as a way to mitigate the problems with the limited availability of land with resources favorable wind and solar, and adequate connection infrastructure. The land issue is considered one of the main problems for the growth of renewable energy in the country, due to the lack of land both for the construction of plants and for the expansion of transmission and distribution systems. In 2016, a draft hybrid generation policy was launched, through public consultation, which resulted, in May 2018, in a national policy on wind-PV hybrid generation. In June 2018, the state of Gujarat established its own policy, with greater detail on the regulation and incentives applied to hybrid projects (ANEEL, 2020a; EPE, 2019a).

Also in May 2018, the first attempt to contract hybrid projects was announced, with an auction aimed at contracting up to 2,500 MW. The event was repeatedly postponed due to lack of interested parties. The developers stated that the established ceiling price was unrealistic, fearing also an increase in project costs, in view of the announcement of import tariffs on PV equipment. In 2019, a second auction was announced, again with demand for 1,200 MW. However, once again the price cap was criticized, with sources claiming that it has driven investors away (ANEEL, 2020a; EPE, 2019a).

United States of America

There are cases in which wind and PV power plants were built adjacent to each other, benefiting from operating synergies, such as the California Pacific Wind (140 MW), Oasis Wind (60 MW) and Catalina Solar (143 MWp) of the company EDF renewables projects. In the state of Minnesota, it was announced in 2017 that an integrated hybrid project would be installed adding 1 MWp PV to 4.6 MW of existing wind farms (Red Lake Falls Project), using GE's Wind Integrated Solar Energy – WISE technology already presented by the company in Brazil, which does not require the use of the PV inverter. However, this project became the target of a legal dispute between the plant's owners (ConEdison) and the local distributor (Otter Tail) over issues related to energy pricing. The companies differ in the cost avoided to the distributor, which serves as the basis for the price of energy that must be paid to the generator in distributed generation projects, such as the case in question (ANEEL, 2020a; EPE, 2019a).

United Kingdom

The Swedish company Vatenfall has installed 5 MW PV power alongside an existing 8.4 MW wind farm in Wales (Parc Cynog Wind/solar farm), and the set has been operating since April 2016. The company reports that the performance of the park has been good, noting that productions have been complementary on a daily basis. The curtailment that occurs due to the lack of margin for connection is allocated to the solar plant, which would be technically easier. The hybridization project received subsidies from the Renewable Obligation renewable energy certificate program, which had subsidized renewable generation in the region since 2002, and was discontinued for new projects in March 2017. With the end of this incentive, the projects PV competitiveness has been reduced, and new projects of this type have not proved viable, even with possible reductions in investment provided by hybridization (ANEEL, 2020a; EPE, 2019a).

China

In 2012, the State Grid company, in partnership with BYD, put into operation a hybrid demonstration project in the city of Hebei, including 100 MW of wind power, 40 MW of PV and 36 MWh of lithium-ion batteries. The aim is to study the application of batteries to stabilize production, and the plant is expected to expand to up to 500 MW of wind, 100 MW of PV and 110 MW of batteries of different technologies, with an estimated investment close to 2 billion US dollars (ANEEL, 2020a; EPE, 2019a).

Australia

In Australia, from the study "Co-location Investigation – A study into the potential for co-location wind and solar farms in Australia" (ARENA, 2016), it was estimated that there could be a reduction in investment between 3% and 13% in a PV plant next to a wind plant compared to a PV plant in another location, while the savings in operation and maintenance would be between 3% and 16%. Figures obtained in the Australian study may indicate a limit to the increase in costs associated with access to the transmission system. The load cut (curtailment) that would be recorded in a PV plant built alongside existing wind farms was evaluated. It was found that there is no general rule for the relationship between added PV power and curtailment, a result similar to that obtained in the EPE study. Some projects in locations with more daytime winds (wind generation more coincident with solar) had less curtailment than others in night winds, as they had smaller capacity factors, that is, there was more idle capacity in the grid, showing the importance of sizing of the project on the results. The comparative cost-benefit analysis of the different regions of Australia considered a dimension such that the curtailment was 5%, evaluating the locations according to the solar resource, with the spot market prices of the considered market, location of projects and economy of scale (ANEEL, 2020a; EPE, 2019a).

Prasad, Taylor and Kay (2017) report on the existence of a significant temporal complementarity of solar and wind resources in Australia, with the Southeast region showing great potential for the future development of wind-solar SHE. In addition, Australia currently has the Kennedy Energy Park project (2018) in North Queensland, which is a pioneering hybrid development of renewable energy (wind and solar) with storage with construction starting in late 2017 and completion of construction by the end of 2019. The project has 43.2 MW wind (12 Vestas V136 turbines of 3.6 MW each and height of 132 m), 15 MW solar (with single axis trackers) and 2 MW of lithium battery storage. According to Froese (2017), Kennedy Energy Park has a financing of US$ 160 million and the project plan intends to reach an installed capacity of 1,200 MW.

International Experience Synthesis

According to EPE (2019a), the international experiences show that the hybrid power plants implementation is not simple, there are difficulties in making projects viable, which have depended on subsidies and incentives, and the insertion of hybrid projects through market mechanisms is still incipient. It is also noteworthy that the electrical systems of each country have specific needs, not necessarily similar to those in Brazil, which make hybridization more beneficial.

WIND-SOLAR HYBRID POWER PLANTS IN THE BRAZILIAN CONTEXT

In the current regulatory framework of BES there are two types of commercialization electricity market: Regulated Contract Environment (*Ambiente de Contratação Regulada* – ACR) and Free Contract Environment (*Ambiente de Contratação Livre* – ACL). The ACR is regulated by ANEEL and Federal government realize energy auctions to make power energy commercialization contracts. Current, Energy auctions are the contraction main way of Federal government to supply Brazilian power demand. In ACL, there are free negotiation between power energy buyers and sellers via *Power Purchase Agreements* (PPAs).

There is still no specific regulation or regulatory framework regarding combined centralized generation in Brazil. However, some technical discussions and public consultations have been held since 2017 with a view to the future implementation of hybrid power plants in the country. The promoters of these discussions are EPE, ANEEL and MME.

Brazilian Discussions Evolution about Hybrid Power Plants

Until June 2021, 16 relevant national documents (Table 01) on the theme of hybrid power plants were publicly disclosed.

Table 01. List of discussions and information about hybrid power plants in Brazil.

Nº	Discussion Brazilian Historic about Hybrid Power Plants	Institutions	Date
1º	**Technical Note Nº EPE-DEE-NT-025/2017-r0**	EPE	04/24/2017
2º	**Technical Note Nº EPE-DEE-NT-011/2018-r0**	EPE	06/11/2018
3º	**Energy Expansion Decennial Plan 2027 – PDE 2027**	MME/EPE	12/28/2018
4º	**Technical Note Nº EPE-DEE-NT-029/2019-r0**	EPE	06/07/2019
5º	**Technical Note Nº 051/2019-SRG-SCG-SRD-SRT/ANEEL**	ANEEL	06/17/2019
6º	**Public Consultation Nº 014/2019**	ANEEL	06/19/2019
7º	**Technical Note Nº 133/2019-SRG-SCG-SRD/ANEEL**	ANEEL	12/30/2019
8º	**Energy Expansion Decennial Plan 2029 – PDE 2029**	MME/EPE	02/11/2020
9º	**Technical Note Nº 079/2020-SRG-SRT-SCG/ANEEL**	ANEEL	07/23/2020
10º	**Regulatory Impact Analysis Report: Nº 002/2020-SRG/SRT/SCG/ANEEL**	ANEEL	07/23/2020
11º	**Public Consultation Nº 061/2020**	ANEEL	10/21/2020
12º	**Energy Systems of the Future: Integrating Variable Renewable Energy Sources in Brazil's Energy Matrix**	GIZ/Germanic Cooperation/MME/EPE/ONS	10/30/2020
13º	**Technical Note Nº EPE-DEE-NT-084/2020-r0**	EPE	12/16/2020
14º	**National Energy Plan 2050 – PNE 2050**	MME/EPE	12/16/2020
15º	**Technical Note Nº 048/2021-SRG-SRT-SCG-SGT/ANEEL**	ANEEL	05/14/2021
16º	**Paper: Combined Wind and Solar Auctions**	EPE/MME/BMWi	05/18/2021

Technical Note Nº EPE-DEE-NT-025/2017-r0

In 04/24/2017, EPE (2017) published a technical note called "Planning Studies for Generation Expansion: Evaluation of the Generation of Hybrid Wind-PV Power Plants – Methodological proposal and case studies". The main objective of this pioneering work was to describe a methodology for analyzing the complementarity between generation from the wind resource and generation from the PV solar resource in the same location where a hybrid enterprise for energy generation can be developed. This technical note proposed to evaluate energy losses (curtailment) when installing a PV project next to an existing wind project, sharing a limited energy flow capacity. The concept of curtailment (or power cut) represented the amount of energy generated and not used due to the limitation of the electrical system for the flow of this energy. The main parameters that influence such power cuts are also analyzed, with the aim of making the best possible use of a possible local complementarity of resources.

The study was focused on local complementarity, aiming at optimization gains in connection investments. It was not the purpose of this technical note to assess the complementarity on a regional scale or portfolio effect of numerous groups of energy generation projects. Five locations in the Northeast region of Brazil were evaluated and proved to have high solar wind potential and energy complementarity (Figure 07). The study did not address regulatory or economic-financial issues.

The metric established was the accounting of the PV production that exceeds the substation's outflow capacity (with a capacity equal to the installed wind power), where it was verified that amount of unused energy is mainly a function of: (i) the characteristics of the resources local energy sources, especially the daily and seasonal wind profile; and (ii) the dimensioning and technical characteristics of each plant. Another important conclusion is that it is not enough to assess the possible resources complementarity (wind profile or horizontal global irradiation, for example), since the power production curve can have different behaviors, depending on the adopted dimension. This becomes clear when analyzing wind production from different wind turbines for the same location. Thus, it is important to assess case by case (each location and each configuration of plants) based on a consistent methodology, taking into account the measurements of resources with discretized bases and for extended periods, in order to contemplate their inter-annual variability.

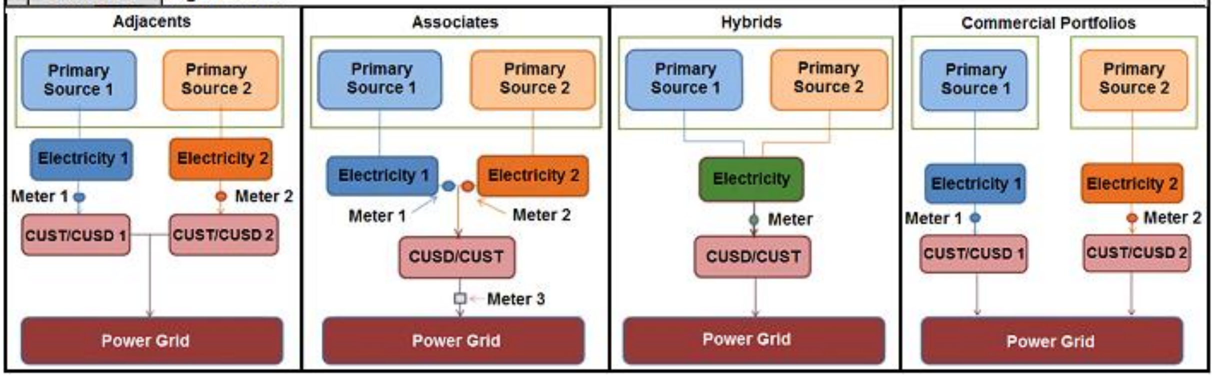
This technical note recommended further studies to: (i) develop a methodology for hiring and accounting; (ii) prepare rules and regulatory conditions for the implementation of projects with installed capacity above the nominal power of the substation to which they are connected; and (ii) Assess the impacts of inserting large volumes of hybrid power plants in the same sub-area of the National Interconnected System (SIN).

Technical Note Nº EPE-DEE-NT-011/2018-r0

In 06/11/2018, EPE (2018) published a technical note called "Generation Expansion Planning Studies: Hybrid power plants – A qualitative analysis of regulatory and commercial issues relevant to planning". This technical note definition of 4 types (Table 02) of hybrid power plants: *Adjacent, Associated, Hybrid* and *commercial portfolios*. This technical note aimed to map the various integrative arrangements and configurations (typologies) of energy sources and discuss their potential benefits and limitations. For each typology, the main barriers to its feasibility were identified (technical, commercial-contractual and regulatory) and identified possible actions to eliminate or reduce them.

Table 02. Types of hybrid power plants.

Types of Hybrid Power Plants		Descritpion
1	Adjacents	Power plants built in close proximity and which can physically share the same land and facilities of restricted interest, but each plant contracts an exclusive capacity for the use of the network compatible with its nominal installed power.
2	Associates	They arise from two distinct energy sources, with complementary production characteristics, which physically and contractually share the infrastructure for connection and access to the transmission or distribution systems, and a flow capacity lower than the sum of the nominal power of the plants may be contracted.
3	Hybrids	When different energy sources are combined in the electric energy production process, there is only a single measurement for the production of electricity.
4	Commercial Portfolios	In which case the plants are not necessarily close and there is no sharing of facilities, being a purely contractual organization.



Technical Note Nº EPE-DEE-NT-029/2019-r0

In 06/07/2019, EPE (2019) published a technical note called “Generation Expansion Planning Studies: Hybrid power plants in the Context of Energy Planning”. This technical note aimed to discuss issues raised after the publication of previous technical notes on hybrid power plants.

Hybrid projects in the context of energy planning have the potential to contribute positively: (i) Hybrid power plants are a possibility to increase the security of the system, (ii) Hybrid power plants have a greater contribution in meeting the maximum demand and this contribution could be considered in the planning, (iii) Hybrid generation is a possibility to make generation less variable, which would mitigate financial impacts for the generation company and improve the stability of the electricity grid. (iv) The sharing of amount of transmission system use (*Montante de Uso do Sistema de Transmissão* – MUST) between two associated plants can bring savings to the generation company, enabling lower energy prices, (v) The sharing of MUST would allow for the optimization of transmission and the postponement of investments in transmission lines. However, it can also result in fines for generation companies if the contracted limit is exceeded, (vi) New hybrid projects with storage capacity (batteries) would help to control energy production.

In the SIN, the current regulation already permits that part of benefits normally attributed to hybrid power plants are obtained, for example sharing lands and construction and operation synergies. Some SIN advantages, for example point demand supply and e systemic security grown too already accessed in recurrence of power plants diversification portfolio of the SIN, thus, this is caused to source energy diversification, but not necessary because physician hybridization. By side of entrepreneurs players, a projects varied portfolio can contribute to mitigate the financials expositions similarly at hybrid or associated projects, despite power plants ware located near among them (EPE, 2019a).

Thus, it understands that association or hybridization of power plants represent innovators models that are possible technically and can eventually to energy price reduction. However, it should look for eliminate barriers to your development and with attention to possible difficult demonstrated by international experience. Too, it should have careful with linked financial risks, directing preferentially to generation company players, in accordance that specificities of each project. (EPE, 2019a). Thus, EPE (2019a) commented that BES players already invest in hybrid power plants development in ACL, but assumed the risks linked this innovation enterprise.

Technical Note Nº 051/2019-SRG-SCG-SRD-SRT/ANEEL

In 06/17/2019, ANEEL (2019a) published this technical note linked with the process 48500.005625/2018-91 (proposal to open a public consultation with a view to collecting subsidies for the Regulatory Impact Analysis – AIR). This subject was the establishment of public consultation aiming to gather subsidies for the elaboration of a normative proposal on the establishment of "hybrid" and/or "associated" hybrid power plants in Brazil. This technical note was a preview to public consultation 014/2019 about hybrid power plants defined by EPE (2018).

Public Consultation Nº 014/2019

In 06/19/2019, ANEEL (2019b) published this public consultation to obtain subsidies for the elaboration of a proposal for a normative resolution that disciplines the implantation and operation of hybrid power plants. The period for submission of proposals and comments was between 06/19/2019 and 8/3/2019. This was the first public consultation made by ANEEL about hybrid power plants in Brazil. This action had 202 contributions of the many BES agents and avulses participations of professional consultants, engineers, academics and others interested.

Technical Note Nº 133/2019-SRG-SCG-SRD/ANEEL

In 12/30/2019, ANEEL (2019c) published this technical note linked with the process 48500.005625/2018-91 and with theme "Regulatory approach for establishment of hybrid and/or associated hybrid power plants". This document consolidated the 202 contributions sanded to Public Consultation Nº 014/2019.

Technical Note Nº **079/2020-SRG-SRT-SCG/ANEEL**

In 07/23/2020, ANEEL (2020a) published this technical note, linked to process 48500.005625/2018-91 and processes 48500.001027/2020-67 (Draft normative act on the regulatory treatment for the establishment of hybrid and associated plants). This technical note was a preview to the second public consultation and a technical fundamental about hybrid power plants. It was a conclusions synthesis from the anterior others technical notes and the first public consultation. The "hybrids" and "associated" hybrid power plants were considering the more benefits types. Thus, they were the focus of the new public consultation.

Regulatory Impact Analysis Report Nº 002/2020-SRG/SRT/SCG/ANEEL

In 07/23/2020, ANEEL (2020b) published these regulatory adjustments for the implementation of hybrid power plants and improvement of the regulation related to the contracting of access to multiple generating plants. Document attached to technical note Nº 079/2020-SRG-SRT-SCG/ANEEL, processes Nº 48500.005625/2018-91 and Nº 48500.001027/2020-67. 07/23. This document was a discussion base to public consultation Nº 061/2020.

Public Consultation Nº 061/2020

In 10/21/2020, ANEEL (2020c) published this public consultation linked with the Processes 48500.005625/2018-91 and 48500.001027/2020-67. This subject was obtaining subsidies for the Regulatory Impact Analysis – AIR regarding the regulatory treatment for the establishment of "hybrid" and "associated" hybrid power plants. The period for submission of proposals and comments was between 10/21/2020 to 12/4/2020. This was the second public consultation carried out by ANEEL regarding hybrid power plants (hybrid and associated). This consultation had a total of 28 participants (agents, industry associations and the ONS) who presented 141 contributions regarding the text of the AIR Report.

Energy Systems of the Future: Integrating Variable Renewable Energy Sources in Brazil's Energy Matrix.

In 2020, EPE in partnership with German entities released a study on the integration of variable renewable sources from the point of view of technological aspects, network procedure, energy and electrical studies, methodological and planning a future horizon of safety and reliability with a possible massive insertion of variable renewable sources in the electrical matrix (GIZ *et al.*, 2020).

The main conclusion of the study indicates that the application of methodologies and tools for planning the next generation expansion will prepare the Brazilian electricity system to accommodate large amounts of variable renewable sources, respecting the criteria of reliability, safety and stability of the system. It also shows that these high levels of variable renewable sources penetration can be achieved while respecting the balance of technical and economic aspects, as well as reconciling long and short-term goals for the expansion and operation of the system (GIZ et al., 2020).

Technical Note Nº EPE-DEE-NT-084/2020-r0

In 12/16/2020, EPE (2020) published a technical note called "Generation Expansion: Wind and PV associated plants – Considerations for calculating the physical guarantee of energy". This technical note performs some simulations to investigate the issues of physical energy guarantee in relation to the hybridization of wind power plants with solar PV power plants and curtailment due to flow capacity constraints.

Currently, the physical energy guarantee for wind and PV plants is defined by MME Ordinance Nº 101, of March 22, 2016. For both, the annual energy production in the long term is estimated, subtracting outages (scheduled and forced), internal consumption and electrical losses. The main distinction is that for wind power plants the average annual energy is considered to be exceeded with a probability of occurrence equal to or greater than 90%, while for PV plants the value is 50%. It is worth emphasizing that there is low inter-annual variability of PV plants, consequently, 50% of these plants tend to be closer to 90%. This difference indicates the difficulty in estimating a single physical energy guarantee for combined generation.

Despite the association of power plants (a new incoming plant and a pre-existing plant), the proposals discussed in this technical standard were based on the premise that each plant would have its own physical energy guarantee. If it was already allowed and there was the sharing of the MUST, a part of the production should be cut and the amount of energy not drained should be deducted in the physical energy guarantee of the new incoming plant that will be associate to the preexisting plant. However, the definition of a single physical energy guarantee presupposes a unified commercialization. This leads to additional challenges linked to contractual and accounting issues discussed in a prior technical note (EPE, 2018). At least initially, this justifies keeping individualized physical guarantees, with due consideration for estimated production cuts.

Combined Wind and Solar Auctions

In 05/18/2021, EPE disclosure a study of a Brazil-Germany partnership, coordinated by Federal Ministry for Economic Affairs and Energy (BMWi) and MME, on the theme Combined wind-solar auctions. On the Brazilian side, EPE, MME, the MRTS consultancy, which was responsible for compiling the document and representatives from academia, participated in the cooperation. BMWi, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and other consultants involved in the theme took part on the German side, as well as India as a guest, with the Solar Energy Corporation of India (SECI) (EPE *et al*., 2021)

International experience shows a growing interest in the promotion of hybrid projects in several energy markets. One of the preferred ways to promote the expansion of new entrants have been through public auctions, which offer either attractive contractual conditions to investors or competition between projects, leading to a reduction in the prices offered to final consumers (EPE *et al*., 2021). The final report is a joint article reporting the experiences of the 3 countries (Brazil, Germany and India) in auctions and hybrid power plants, with recommendations for progress of the theme.

Technical Note Nº 084/2021-SRG-SRT-SCG-SGT/ANEEL

In 05/14/2021, ANEEL (2021) published this technical note with subject “Analysis of contributions received in Public Consultation N^{o} 061/2020 and proposal to open the second phase of the Public Consultation with a view to regulatory treatment for the establishment of hybrid and associated plants”. This note organized and analyzed the suggestions obtained in Public Consultation Nº 061/2020. The conclusion reached was that an improvement must be made to the current rules for the insertion of provisions related to the implementation of "hybrid" and "associated" plants, according to the analysis contained in the AIR Report and the draft proposal for revision of the regulations according to the contributions of the last public consultation.

EPE (2019, 2020) and ANEEL (2020a) consider that hybrid power plants and associated plants are the types with the greatest potential for benefits for the BES. Brazil already has many wind and solar power plants deployed in the Northeast, and many of these have the possibility of being hybridized in the future.

Paper: Combined Wind and Solar Auctions

This action was a Brazil-Germany partnership, coordinated by MME, EPE and BMWi, and the final report was the collective paper related the experiences of 3 countries (Brazil, Germany e India) in auctions and hybrids power plants, with recommendations to advance about this theme.

Energy Expansion Decennial Plans 2027 & 2029 and National Energy Plan 2050

Typically, PDEs are plans prepared annually by EPE with an energy planning horizon and guidance for 10 years. The PDEs 2027 and 2029 already make some quotes about the future use of hybrid power plants. This indicates that creation of a specific regulation to viable hybrid power plants in Brazil probably that will be only be a matter of time.

In 10/21/2020, the EPE and MME (2020) published the PNE 2050. Prepared by EPE based on MME guidelines, the plan is an instrument to support the planner's long-term strategy design in relation to the expansion of the energy sector. For this, a set of recommendations and guidelines to be followed throughout the 2050 horizon is presented. This is the second energy plan prepared for Brazil and cites hybrid power plants as a future possibility for the BES.

BRAZILIAN EXAMPLES OF WIND-SOLAR HYBRID POWER PLANTS

EPE (2017) identified 5 relevant complementarity locations in the Brazilian Northeast (Figure 07). In adition, Santos *et al.* (2020a, 2020b) inform that there are 2 examples of wind-solar hybrid power plants implemented in the municipalities of *Tacaratu* (Pernambuco) and *Caetité* and *Igaporã* (Bahia). There are also 4 other examples of previous studies and/or pilot projects for future hybrid power plants, respectively, in the municipalities of: *Parazinho* (Rio Grande do Norte); *Araripina* (Pernambuco); *Curral Novo do Piauí* (Piauí) and *Casa Nova* (Bahia).

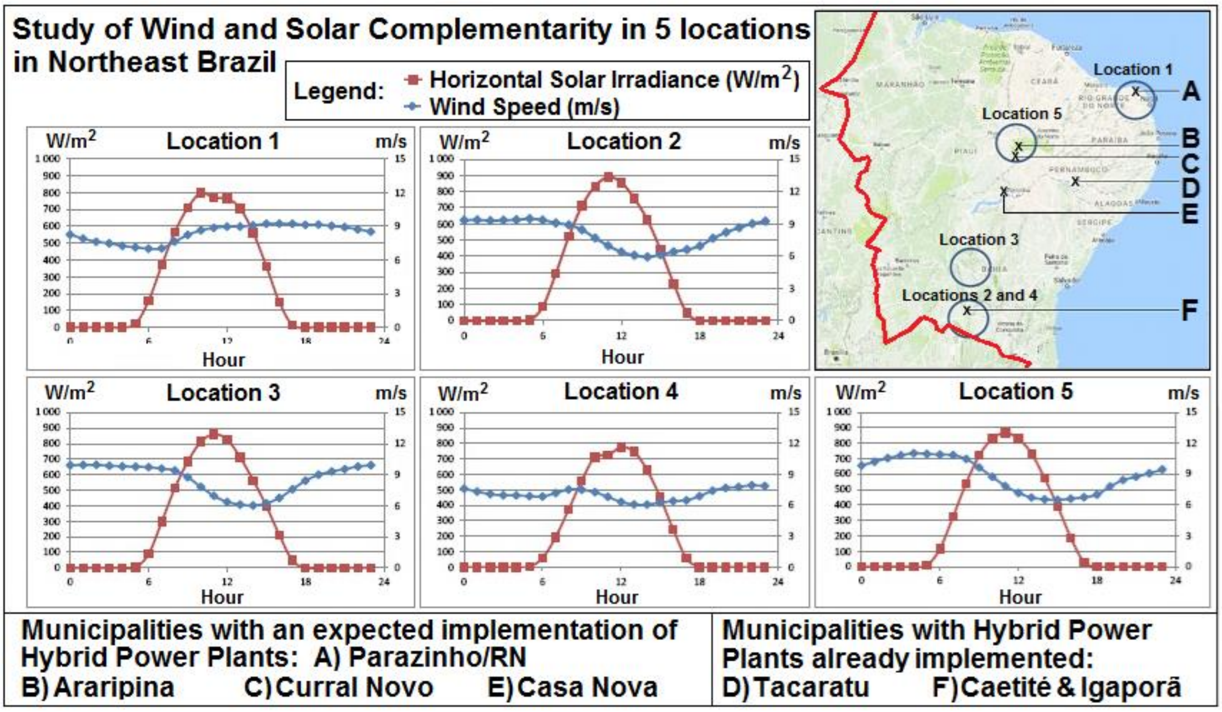


Figure 07. Complementarity in 5 locations in the Northeast Region (EPE, 2017) and municipalities of the 5 examples of wind-PV hybrid power plantes. Adapted.

Two Existents Wind-Solar Hybrid Power Plants

Hybrid power plant in Tacaratu. This hybrid power plant (Figure 08) belongs to Enel Green Power do Brazil (EGPB) and has an installed capacity of 80 MW from wind power (starting into operation in 2014) and 11 MWp solar (starting into operation in 2015). According to the EPE (2018) classification, it would be an *adjacent* hybrid power plant, as it resulted from the junction of three wind farms with two solar plants, where the wind and solar plants were contracted in different energy auctions, one national and the other state, respectively. By technical-commercial decision of EGPB, the plants were hybridized by sharing the same substation and transmission lines.

Figure 08. Hybrid power plant in Tacaratu/PE. Source: Enel Green Power Brazil, 2018. Adapted.

The hybrid plant in Tacaratu/PE is the first wind-PV hybrid project connected to the electricity grid in operation in Brazil and is an example of hybridized wind farms with addition of PV farms: installed capacity: 87.9% wind and 12.1% PV. The positive result was an increase in generation of more than 20% above the exclusively wind generation between 10:00 am and 2:00 pm. This gain is compatible with estimates of 20% by Studzinski *et al.* (2017).

Hybrid power plant in Caetité and Igaporã. This hybrid plant belongs to Renova Energia and has an installed capacity of 21.6 MW from wind and 4.8 MWp solar (Figure 09). It is a research and development project financed by the Financier of Studies and Projects (FINEP) in the amount of R$ 108 million and will start operating in 2016.

Figure 09. Hybrid power plant in Caetité and Igaporã/BA. Source: Renova Energia (2017). Adapted.

According to the EPE classification (2018), it could be a *hybrid* power plant, as it is an example that was conceived from the beginning as a hybrid plant with an installed capacity of

81.8% wind and 18.2% solar PV. During the winter, there was more wind generation, and in the summer, there was an increase in solar generation. After one year of operation, it was found that between 11:00 am and 3:00 pm, the hybrid generation presented increases above 30% in relation to the wind generation alone. This result surpassed the 20% estimates made by Studzinski *et al.* (2017).

Fuor Futures Pilot-Project of Wind-Solar Hybrid Power Plants

Future pilot-project hybrid power plant in Araripina. Between 2015 and 2017, the company *Casa dos Ventos* (2016, 2017) implemented the wind complex *Ventos do Araripe* III (359 MW), located in the municipality of Araripina, in the state of Pernambuco and on the border with state of Piauí. The wind complex Ventos do Araripe III received an investment of R$ 1.8 billion, is composed of 14 wind farms (9 in Piauí and 5 in Pernambuco) and with a total of 156 wind turbines and its inauguration was on 06/09/2017. According to Pontes (2017a), Casa dos Ventos and General Electric Renewable Energy (2017), these two companies partnered to introduce a new technological platform WISE in Brazil. Pontes (2017b) commented that WISE is a hybrid combination of wind and solar energy to allow a stable supply of energy from the production of each source whenever necessary. The first phase of the project integrates 1 MW solar PV in 4 wind turbines. If this is replicated in the 156 wind turbines, it would be possible to add 120 MW of solar installed capacity to the Ventos do Araripe III wind farm. According to the classification of EPE (2018), this future complex will be adjacent hybrid power plants. Casa dos Ventos foresees the future possibility of hybridizing this wind complex with solar PV energy in up to 1/3 of the installed capacity, if a new pertinent regulation is created and the flow margin via auctions make such action feasible.

Future pilot-project hybrid power plant in Parazinho. Asa Branca III wind farm is located in the municipality of Parazinho/RN. It belongs to Paraná Energy Company (*Companhia Paranaense de Energia* – COPEL), has 10 wind turbines and a total installed capacity of 27 MW. According to the Ministry of Planning (2018) of the Federal Government, this project was completed in 2018 and the investment for its implementation was R$ 120 million. Rodrigues *et al.* (2018) carried out a simulation of energy generation with the addition of a 6.7 MWp PV power plant to optimize the total energy production of the wind farm, making it a hybrid project in the future. According to the EPE classification (2018), this future hybrid project will be an adjacent hybrid plant.

Future pilot-project Hybrid power plant in Curral Novo do Piauí. This future hybrid plant is projected to add 68 MW PVs to an installed capacity of 535.1 MW wind (18 wind farms with 249 wind turbines). ANEEL (2020a) intends to study the impacts in terms of regulation of a PV plant associated with other wind farms through this pilot project. According to the EPE (2018) classification, this corresponds to an *adjacent* hybrid power plant.

Future pilot-project hybrid power plant in Casa Nova. The São Francisco Hydroelectric Company (*Companhia Hidroelétrica do São Francisco* – CHESF) (2020) will invest R$ 90.8 million (US$ 16.3 million) in the development of a hybrid power plant, combining renewable sources and forming an intelligent system integrating wind and solar technologies and storage, enhancing the process of generating electricity. The power plant in the Casa Nova I wind farm (27 MW of installed capacity with 18 wind turbines of 1.5 MW each) will be hybridize with solar energy.

FEASIBILITY INDICATORS OF THE HIBRID POWER PLANTS

Discussions about the creation of specific regulation or the realization of specific auctions to hybrid power plants. The wind-solar hybrid power plants are shaping up as interesting opportunities for electricity generation projects in Brazil. In this context, it is interesting that decision makers about the implementation of generation projects (usually directors, managers, analysts or consultants from the private sector) have indicators or criteria to decide on the feasibility of this type of project. The technical-academic literature available on this topic shows several indicators to aid decision-making, among those mentioned, it is possible to suggest 12 indicators, which can be aggregated into 5 dimensions: a) technical, b) economic, c) environmental, d) social, e) regulatory (Table 03).

Table 03: 12 feasibility indicators grouped into 5 Dimensions.

Nº	Dimensions and Indicators	References
A	**Technical Indicators Group**	
1	**Wind Resources (Wind Speed)**	Bulhões, Santana e Santos (2020), Júnior *et al.* (2020a), Ke *et al.* (2013), Lima (2016b), Wu e Geng (2014), Höfer *et al.* (2014), Abreu e Oliveira (2011).
2	**Solar Resources (Solar Irradiation)**	Bulhões, Santana e Santos (2018), Lima (2016b), Wu e Geng (2014).
3	**Complementarity**	Luz e Moura (2019a, 2019b), Monforti *et al.* (2014), Hoicka e Rowlands (2011).
4	**Transmission Lines Density**	Bulhões, Santana e Santos (2020, 2018), Júnior *et al.* (2020a), Ke *et al.* (2013), Wu e Geng (2014), Höfer *et al.* (2014).
5	**Transportation Ways Density**	Bulhões, Santana e Santos (2020, 2018), Ke *et al.* (2013), Höfer *et al.* (2014).
6	**Demography Density**	Bulhões, Santana e Santos (2020, 2018), Höfer *et al.* (2014).
B	**Economic Indicators Group**	
7	**Economic-Finance Viability**	Bulhões, Santana e Santos (2020, 2018), Júnior *et al.* (2020a), Carvalho, Guardia e Lima (2019), Luz, Moura e Almeida (2018), Qolipour *et al.* (2017), Rozali *et al.* (2017), Wu e Geng (2014), Abreu e Oliveira (2011).
8	**Industrialization Level**	Bulhões, Santana e Santos (2020, 2018), Schmitz *et al.* (2016).
C	**Environmental Indicators Group**	
9	**Relative Available Area**	Bulhões, Santana e Santos (2020, 2018), Júnior *et al.* (2020a), Watson and Hudson (2015), Ke *et al.* (2013), Conde (2013).
D	**Social Indicators Group**	
10	**Development Municipal FIRJAN Indicator – IFDM**	Bulhões, Santana e Santos (2020, 2018), Schmitz *et al.* (2016).
E	**Regulation Indicators Group**	
11	**Regulation/Current Legislation**	Santos *et al.* (2020a, 2020b); Camargo *et al.* (2019); Santos *et al.* (2017).
12	**Legal Security**	Santos *et al.* (2020a, 2020b); Santos *et al.* (2017).

The 12 indicators chosen are consistent with the guidelines of the Global Reporting Initiative (GRI) and the Brazilian Institute of Social and Economic Analysis (IBASE). Based on these 12 suggested indicators and/or other indicators that decision makers deem relevant, it is possible to adopt some decision-making method or create some new decision-making method capable of producing a global feasibility index to decide on the implementation of wind-solar hybrid power plants in Brazil.

COMMENTS AND CONCLUSION

Brazil has a clean electrical matrix compared to the world context. However, it has the need to expand and diversify the national electric matrix in favor of supply security, maintenance of a clean matrix and compliance with COP 21 targets. The existence of a great energy potential of wind-solar complementarity to be explored by combining centralized generation in Brazil was confirmed. Brazilian Northeast is the region with best conditions to implantation of wind-solar hybrid power plants.

Nowadays, there is still no specific regulation to combining centralized generation, despite this question was beginning officially discussed from 2017. In this context, there are three possible scenarios in relation to centralized combined wind and solar PV generation via hybrid projects at SEB: a) maintenance of the current regulatory framework; b) hybridization of existing wind or solar PV projects, c) specific auctions of hybrid projects from the original project.

Already there are a total of 6 cases of wind-solar hybrid power plants were identified: 2 projects implemented and 4 futures pilot-projects plans. Some decision-makers of BES players are interested in wind-solar hybrid power plants and signalizing the aims to hybridization some wind power plants with solar FP in the next years via ACL, same in case of there no specific regulation.

The Brazilian potentials for wind and solar power generation are high and there is a complementarity between them, especially in the Northeast region. In these circumstances, the combination of wind and solar PV technologies for centralized power generation by hybrid power plants is a possibility of contributing to the BES to meet part of its needs. Thus, combined centralized generation via wind-solar hybrid power plants is an interesting new opportunity for Brazil expands and optimizes your electricity matrix.

NOMENCLATURE

ACR – Regulated Contract Environment
ACL – Free Contract Environment
AIR – Regulatory Impact Analysis
ANEEL – National Electric Energy Agency
BEN – National Energy Balance
BES – Brazilian Electricity Sector
BMWi – Federal Ministry for Economic Affairs and Energy
BNEF – Bloomberg New Energy Finance
CEPEL – Electric Energy Research Center
CG – Centralized Generation
CHESF – São Francisco Hydroelectric Company
COPEL – Paraná Energy Company
COP 21 – 21st Conference of the Parties
CO_2 – Dioxide of Carbon
ESMAP – Energy Sector Management Assistance
EPE – Energy Research Company
FIRJAN – *Federação de Indústrias do Estado do Rio de Janeiro* (Industrial Federation of the State of Rio de Janeiro)
GHG – Greenhouse Gases
GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit

GRI – Global Reporting Initiative
IBASE – *Instituto Brasileiro de Análises Sociais e Econômicas* (Brazilian Institute of Social and Economic Analysis).
IEA – International Energy Agency – IEA
IFDM – *Índice FIRJAN de Desenvolvimento Municipal* (Development Municipal FIRJAN Indicator)
INCT-Clima – National Institute of Science and Technology for Climate Change
IPCC – Intergovernmental Panel on Climate Change
IRENA – International Renewable Energy Agency
LCOE – Levelled Costs of Electricity
MME – Mines and Energy Minister
MUST – *Montante de Uso do Sistema de Transmissão* (Amount of Transmission System Use)
PDE – Energy Expansion Decennial Plan
PNE – Energy National Plan
PPAs – Power Purchase Agreements
PV – Photovoltaic
SECI – Solar Energy Corporation of India
SIN – National Interconnected System
UNFCCC – United Nations Framework Convention on Climate Change
UK – United Kingdom
UN – United Nations
USA – United States of America
WISE – Wind Integrated Solar Energy

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