Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Combined Wind and Solar Auctions

Imprint

Commissioned and published by
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Registered offices
Bonn and Eschborn, Germany

Project: Bilateral Energy Partnerships in Developing and Emerging Countries
Contact: German-Brazilian Energy Partnership
SCN Quadra 01, Bloco C, Sala 1501
70711-902 Brasília – DF, Brazil
Kristina Kramer
E-mail: kristina.kramer@giz.de
Stéphanie Gomes
E-mail: stephanie.gomes@giz.de
Website: www.energypartnership.com.br
Tel.: +55 61 2101 2170

As at
27/05/2021

Design
Vaz Gontijo Consultoria, Brasília
Edelman GmbH, Berlin

Photo credits
André Pereira: page 5

Text
MRTS Consultoria

The creation of this publication was supported by EPE (Empresa de Pesquisa Energética).
It was published within the scope of the German-Brazilian Partnership, which is a joint initiative of BMWi (Federal Ministry for Economic Affairs and Energy) and MME (Ministério de Minas e Energia).

GIZ is responsible for the content of this publication.

On behalf of the
Federal Ministry for Economic Affairs and Energy (BMWi)

Content

Acknowledgments

The German-Brazilian Energy Partnership would like to thank all the Brazilian, German, and Indian experts who participated in this Task Force on “Combined Wind and Solar Auctions” for sharing their experience, their unparalleled knowledge and their invaluable insights.

Abstract

This work discusses the main aspects of combined auctions for solar and wind sources in the context of the Brazilian Power Sector, based on international benchmarking from the German and Indian experiences. The combination of different sources in a same project – hybrid projects - emerges from an existing local complementarity in their generation profiles, resulting in a more stable output and, consequently, a reduced financial risk of energy trading. Besides, hybrid projects can also benefit from sharing land and facilities, as well as construction, maintenance, and operation workforce, thus optimizing power plants CAPEX and OPEX. Further gains can also emerge from more efficient use of the transmission network when power plants are installed in the same location or sharing grid connection.

The Northeast region of Brazil concentrates most of the country's wind installed capacity and is a relevant example of local complementarity among solar and wind sources. Due to the potential for hybridization of existing projects and the implementation of new hybrid plants into the national market, the regulator (ANEEL) has intensified public discussions with market agents to address the necessary regulatory adjustments for the insertion of these types of projects in the national market. As a support to the discussions, the Technical Notes published by the Energy Research Company (EPE) also stand out, having supported important discussions, such as the typification of these types of plants, in addition to technical, commercial, and regulatory issues.

In order to promote these types of projects in many markets, auctions have been chosen as the main energy contracting mechanism. The international experience shows a diversity of the auction models, depending on the technical and economic situation of a specific market and its peculiarities regarding market design, beyond the natural vocations of the generation profile of local resources.

India, for example, has already successfully procured hybrid projects in two types of auctions. Initially, through a specific hybrid project auction, and lately through general auctions in which hybrid projects compete, side by side, with renewable solar or wind sources. India also holds customized auctions to meet the demands of distribution companies, with specific peak load and 'round-the-clock' electricity supply requirements. On the other hand, Germany has held recently the so-called 'innovation auctions' where combining projects have been procured. Brazil is another successful case in which auctions have managed to make wind and solar prices more competitive in market terms, fostering even decentralized and voluntary investments into the free market. Currently, both sources are at the same level of economic attractiveness, indicating that in the possibility of holding auctions with the participation of hybrid projects, one could consider the three types of projects (solar and wind hybrid, solar and wind projects) competing in the same event.

Despite focusing on auctions for solar and wind sources in hybrid projects, this work also discusses the international experience in combining such sources with storage facilities. The combination of renewable sources with storage allows a greater reduction of the power plant's output variability, and thus, a more optimized usage of its connection to the grid, a more flexible operation and better contract management. Academic references have also shown promising results on the combination of solar and hydropower with water reservoirs. Besides, this work also presents some discussions related to the system's operation and planning when considering the participation of hybrid projects.

Figure 1. Adjacent power plants located at Areia Branca – RN, Brazil: Floresta 1, 2 and 3 photovoltaic power plant – Engie Solar. Mar e Terra (left) and Areia Branca (right) wind power plants – AES Brasil.

1. Context

The German-Brazilian Energy Partnership was established as a platform for cooperation between the Ministry of Mines and Energy (MME) and the German Ministry of Economic Affairs and Energy (BMWi), implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. It provides a forum for high-level political dialogue and brings together representatives from different sectors to support a broader use of renewable energies and energy efficiency.

To this end, regular working group meetings are held, strengthening the bilateral dialogue and cooperation between Brazil and Germany in the energy sector. In September 2020 the Working Group on Renewable Energies selected "Combined Wind and Solar Auctions" as one of the topics for further exchange. Both governments agreed on convening a task force consisting of Brazilian and German experts from government, business, and academia to discuss a series of guiding questions, pre-defined by both governments as follows:

1. A clear perspective on the net benefits of combined wind and solar plants (same site and sharing connection to the grid) is key for regulation and auction design. Cost reductions both in terms of CAPEX and OPEX are expected, due to synergies during construction and operation. On the other hand, simultaneous generation affects the energy yield of combined wind and solar plants, due to curtailed energy, bringing opportunity costs. Are there studies to provide evidence of how competitive these solutions would be when compared to non-combined wind and solar PV plants?

2. What are key choices when designing an auction that allows combined wind and solar plants to bid? Considering we want to have an auction on which combined wind-solar plants may participate, what are the possibilities regarding its design, including:

> **a)** product separation - wind/solar products or single product.
>
> **b)** combined/conditional bids - same projects bidding as single or associated/hybrid, for example.
>
> The designed auction should avoid market reserves and should be able to allow the project developers to incorporate the association/hybridization benefit onto their bids.

3. Are these auctions expected to result in a dominant source (wind or solar PV)?

4. Would it be the case for allowing other combined technologies, such as storage and biogas, or just wind and solar?

5. Is the regulatory framework ready for combined wind and solar auctions? Access to the grid, grant by the regulator, etc.

6. Do they affect the system operation in any way?

7. Do these combined wind and solar affect system planning in any way?

The first meeting of Brazilian and German experts of the Task Force on "Combined Solar and Wind Energy Auctions" took place virtually on December the 3rd, 2020, and allowed both countries to share their experiences on the topic. However, as experiences with combined wind and solar auctions are limited in Germany and Brazil, the suggestion was made to extend the invitation to experts from India. The second Task Force meeting took place in a virtual format on March 2nd, 2021, as a trilateral exchange between approx. 20 experts from Germany, Brazil and India, focusing on question Nº 2.

Based on the results of both Task Force meetings, the present paper discusses and addresses key points related to benefits of hybridization of generation plants, peculiarities of combined auction design, necessary improvements to the regulatory framework and implications for operation/expansion planning.

2. Introduction

Enabling renewable sources for electricity generation and consumption requires investment attraction, and the capability to optimize the profitable exploration of available natural resources from an environmental, economic, and social point of view.

Wind and solar generation plants have spread worldwide in the last decade, as investment and operation and maintenance costs of such plants decreased. Some countries have achieved maturity of their internal supply chains, to meet the demand of greenfield project's developers. The adoption of public auctions for renewable electricity procurement has been a relevant tool for price reduction.

From 2017 to 2018, about 55 countries were using auctions for renewable electricity acquisition. One third of them had done so for the first time during that period. By the end of 2018 about 106 countries had undertaken renewable energy auctions at least once (IRENA, 2019a).

These numbers show the evident success of auctions to procure electricity investments, especially when it comes to renewable sources. This success is related mainly to the diversity of possible auction designs, which make them adaptable to specific situations concerning natural resources, financial/economic conditions, and electricity market design of each country or region.

This observation leads to one first conclusion: there is not a single auction design to be applied to every general procurement situation Adaptation to fit specific requirements is always needed, and flexibility of auction design is essential to achieve this goal.

According to IRENA (2019a), prices of renewables are a consequence of four main factors, and auction design is one of them. However, renewable power potential, financial conditions and local policies are essential as well, and thus, it is not enough to focus only on auction design. Policymakers need to consider the whole context including investor aptitude and risk allocation, in order to get the best result from a bidding process delivered by the auction.

Sometimes price is not even the only attribute to be considered when procuring electricity. There is a need to match output to the load curve. In these situations, lower prices do not necessarily lead to the best results in the biding process and an undesirable "winner's curse" may occur with serious consequences to the accomplishment of the generation plant if auction resulting prices do not properly cover developers and investors costs and risks.

USAID (2019) states that preparing and implementing auctions requires previous definition of objectives to be achieved from the process, in addition to market understanding, institutional capabilities and knowledge on project development cycle. The auction design is a consequence of these factors and must be supported by comprehensive knowledge of local conditions.

Combined auctions require additional attention and specific knowledge since they insert additional variables and possibilities to be delivered by the auction design. The combination of more than one generation source considering energy storage in the same auction allows developers to take advantage of complementary generation – as well as of price arbitrage, when storage systems are considered. Thus, in these cases it is necessary to prevent windfall profits, cross-subsidies, and pre-defined technological quotas, as EPE pointed out (2018).

Nonetheless, it is important not to make auctions rules too strict, which would inhibit interested investors and prevent consumers to take advantage of the benefits represented by the synergy among different renewables and with coupled storage systems.

The aim of auction design in combined source auctions must be to achieve the optimal point of the trade-off curve formed by the investors risk aversion and the propensity of final customers to pay for the benefits of the plants – which in this case includes the complementarity of combined solar-and-wind plants, considering avoided costs related to other expansions alternatives.

As relevant as auction design is the timely implementation of the projects, in accordance to contractual obligations. "Winner's Curse" drives to "Off-Taker's Nightmare" when project development schedules suffer undesirable postponements, or the plant underperforms during operation.

These situations must be prevented. It is best to treat them in advance, during pre-auction procedures for the qualification of either developers or off-takers. Qualification requirements should ensure that previous experience, technical qualification, and financial capability are properly certified.

3. Combined Wind and Solar Plants

Renewable generation variability directly impacts the asset's cash flow, whenever the actual generation curve does not match perfectly to selling contracts curve profile, which leads to involuntary exposures in the short-term market.

From the investors' perspective, one hedging strategy to generation variability is to explore portfolios - and hybrid projects - combining power plants with different seasonal and/or locational generation patterns, where the complementarity between such standards can be explored to mitigate the portfolio/project generation risk and improve financial results under a risk-return perspective.

The studies on complementarity between renewable resources in Brazil, from a statistical and economic points of view, have shown that there is high potential to be explored, by means of hybrid projects (plants in the same location) or commercial portfolios (plants in multiple locations).

For example, Molnár & Camargo (2015) applied the probability theory of copulas functions to evaluate wind and hydro complementarity in different regions of Brazil and showed a high complementarity pattern between wind production in the entire Northeast region and hydro generation in the Northeast, North, and Southeast regions. Besides, though the South region wind production is not complementary to Brazilian overall hydro production, but it is complementary to the South hydro production.

Bagatini et al. (2017) observed the complementarity between hydro, wind and solar energy resources in the state of Rio Grande do Sul, in the South region of Brazil. Cantão et al. (2017) presents hydro-wind correlation maps of Brazil, where we can see a strong complementarity between the stream flows at the left margin of the Amazon River and the wind speed of Northeastern and Southernmost regions. EPE (2016) pointed out that expansion planning of Brazilian electricity system should consider the complementarity between resources and different regions.

Under a risk and return perspective, research from Neto et al. (2017) and Camargo et al. (2020) show that portfolios composed by hydro-wind-solar can result in a generation profile that mitigates the portfolio risk. The same applies for portfolios of wind power plants in different locations in Brazil.

The locational complementarity effect between the renewable sources is studied by Velloso et al. (2019), where it concludes that the installation of a solar power plant in the hydropower plant of Sobradinho could add expressive amounts of energy to the actual power generated but using an area smaller than 0.5% of its water reservoir surface. This improvement is justified by the complementarity effect.

Campos et al. (2020) analyzes the capability of a hybrid wind + solar + storage power plant in supplying the power demand of Brazilian Northeast region. The results show that wind and solar resources are consistently complementary in the region. Also, it presents that the solar-wind complementarity, together with energy storage, can lead to a reduction of up to 11% in transmission capacity demand.

The solar-wind complementarity in same locations at the Northeast region of Brazil is assessed in two technical documents published by the *Empresa de Pesquisa Energética* (Energy Research Company - EPE). EPE (2017) studies the curtailment obtained when a solar power plant is combined to an existing wind power plant under an associated project scheme. Also, local wind-solar complementarity is studied at EPE (2020) to support the proposal for calculating the physical guarantee of associated projects. Figure 2 shows the regional wind-solar complementarity in different locations at the Northeast region, elaborated with basis on power plant operations data in these regions. The data was provided by the *Operador Nacional do Sistema* (National System Operator - ONS)[1].

A long-term aspect to be observed about complementarity lies on the behavior of sources generation over time. Climate changes may affect generation conditions, as shown in Fant et al. (2016). In a recent study carried out by GIZ & MME (2020), it was observed that climate changes may affect inflow in certain hydrographic basins in Brazil, reducing its complementarity with other sources such as wind and solar. Signs of changes in the hydrological regimes and in the intensity of the wind and solar incidence bring risks that should be observed.

Besides the energy trading benefits, the locational and daily complementarity effect between PV solar and wind resources brings about the discussion of more efficiency in the transmission installed network utilization.

[1] http://www.ons.org.br/paginas/resultados-da-operacao/boletins-da-operacao

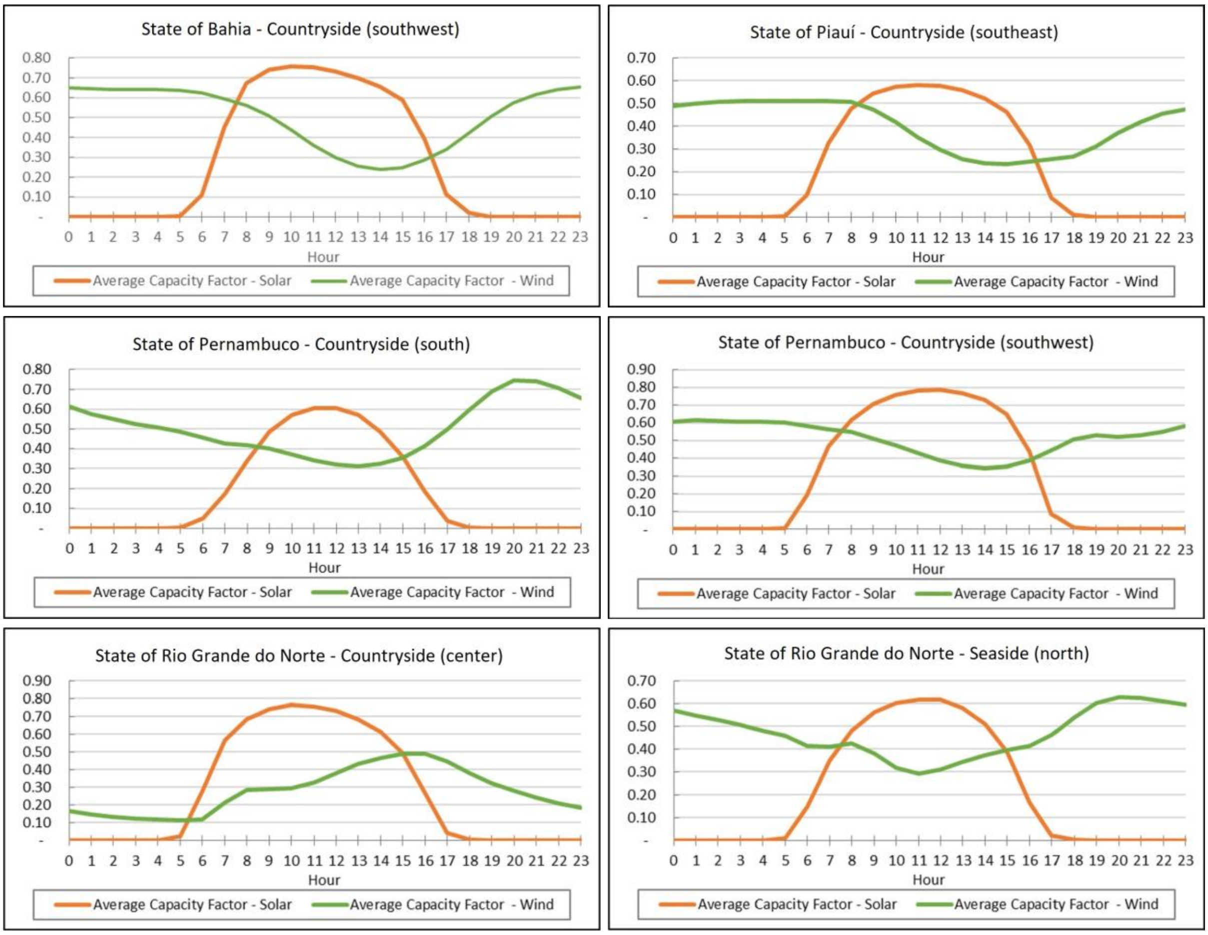

Figure 2 – Regional Wind-Solar complementarity in different locations of northeastern Brazil.

As daily generation from these resources is seasonal, there are times when the transmission capacity becomes underused, due to exceptionally low or even null generation (as with solar during the night). Despite this fact, under the current regulatory regime, both PV solar and wind plants are required to contract a transmission capacity matching their nominal installed capacity of the power plants.

An optimization of the transmission capacity is needed because the grid connection is one barrier to wind plants development in many locations, especially in the Brazilian Northeast region, as we recently saw, when limited availability could be observed in some power substations, whose remaining capacity is low (ONS, 2018).

As a result, sharing the network connection brings advantages to the agents, who currently face constraints to expand their power plants, and to the system as a whole, because of the increase in the use of the hosting capacity of the grid.

Besides potential gains from reduced transmission capacity demand and energy trading benefits from a more stable generation profile, the wind-solar hybrid plant also holds financial benefits from CAPEX and OPEX cost savings. These savings stem from sharing land, infrastructure, grid connection, technical and control support, as well as from advantageous operational, and maintenance synergy that leads to cost reduction (NREL, 2020).

EPE's study published in 2018 defined possible types of hybrid power plant models in accordance with project specifications (EPE, 2018). In the first case, entitled Adjacent Plants, the power plants are constructed next to each other and may share the land and some facilities of restricted interest, providing CAPEX and OPEX cost savings. However, from the system's perspective, this case represents two separate plants, once there is no sharing of generation equipment. Plants in this case do not share the grid connection, having each one its own metering system.

The second case, denominated Associated Plants, consists of two (or more) plants of different energy resources with complementary production, constructed nearby and that physically and contractually share the grid connection infrastructure.

The third model represents the Hybrid Project, where the energy resources are combined at the production process, in such a way that it is not possible to determine the source of the generation from each plant component of the hybrid arrange. This case leads to a single metering system.

The fourth and last category describes the portfolios composed of power plants with different seasonal and/or locational generation patterns previously discussed. This framework, unlike the others, does not involve physical proximity and/or equipment sharing. It's characterized only by a contractual trade that aims to mitigate involuntary exposures to the short-term market, and investor risk management is provided by its own contracting structure in a commercial basis. The Figure 3 illustrates each case described above.

For all these options, the possibility of considering the concepts of hybrid projects depends on the interest of electricity policy makers. For instance, arrangement (d) is considered as hybrid project for combined auctions in India, but it is considered usual commercial portfolio and not treated as hybrid project in Brazil.

In other countries, such as the USA and Australia, the composition of projects with a generation source and a storage system (e.g., Wind + storage; Solar + storage) is typified as a hybrid project. In the concept adopted in Brazil, the interpretation is that hybrids are made up of two or more sources of generation (and may even have a storage system attached), as explained above.

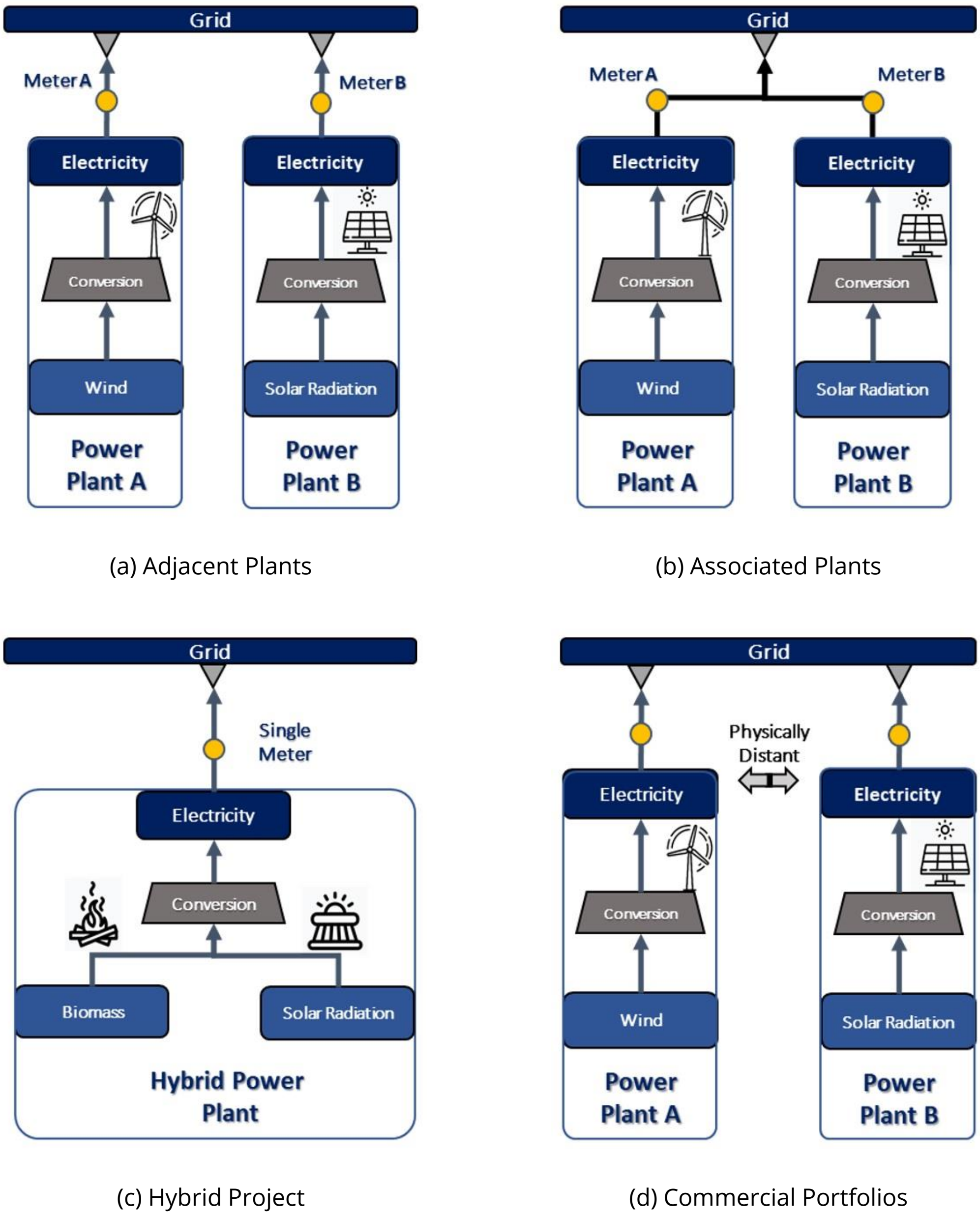

Figure 3 – Hybrid power plant models in accordance with project specifications. Adapted from EPE (2018)

4. Combined Wind and Solar Auctions

The experiences with combined auctions in Germany, India and Brazil have different characteristics, such as the technical constraints of the projects and the criteria for minimum participation of each source in the composition, required for the eligibility of projects in the procurement process.

Hybrid Auctions – Germany's Experience

As there is relevant wind power generation in the northeastern region of Germany, and as the transmission infrastructure is not prepared to transport all this generation to consumption centers clustered in the south, a constraint on the maximum quantity of wind power to be auctioned in the north was defined. This measure has been adopted to align wind capacity additions to Germany's transmission grid development (IRENA, 2019a).

Despite recently reviewing its *Renewable Energy Act* (Erneuerbare Energien Gesetz - EEG), as well as other European countries, Germany does not have specific regulations for hybrid projects implementation (Appunn, 2020a).

In the recent past, there was a governmental policy to promote pilot projects combining batteries with solar panels, via subsidized interest rates. However, this only applied to small and medium-sized facilities (European Commission, 2018).

In 2019, Germany's federal government adopted the *Innovation Auction Ordinance* (Innovationsauschreibungsverordnung), to implement new auction and remuneration models. For the first time, a market premium for renewable sources was offered, instead of support payments to generators in case of negative prices. In this *innovative model*, combined projects could compete because of being considered a technological innovation.

In September 2020, seeking for new investments, the German Federal Network Agency (Bundesnetzagentur - BNetzA) promoted an "*innovative auction*" (Innovationsausschreibungen) for energy, procuring 677 MW of installed capacity. Among the winners, 28 were combined projects, amounting to 394 MW of installed capacity, with 27 projects combining solar with storage and one project combining wind with storage. The auction's winners' projects received between 1.94- and 5.52-euro cents per kilowatt-hour (ct/kWh), in addition to the market's remuneration (Dierks, 2020).

Two auctions were scheduled for 2021, one was held in April and the other will be in August. The objective is to contract 250 MW, with a maximum payment of 7.50-euro cents per kWh (Bundesnetzagentur, 2021a). In these auctions, only hybrid projects, or renewable plants with storage may participate.

In addition, the rules state that the projects must have at least wind or solar sources, and the plant output must take place through a single grid connection point. Also, bids are valid only for projects that are not yet in operation (until the auction) and combinations must be at least 751 kW, with no minimum size for each component on the combination (Bundesnetzagentur, 2021b).

The April 2021 Innovation Auction was two times oversubscribed. For the 250 MW capacity offered to be built, 43 bids were received, totaling 509 MW. All the bids were for solar PV systems with energy storage technology. It selected 18 winning bids with a total bid amount of 258 MW, with fixed market premiums agreed upon as ranging between €0.0333 to €0.0488 per kWh, and a volume-weighted average of €0.0429 per kWh, that means a discount of about 57% on the maximum expected price.

As noted, hybrid projects in Germany are in the early stages of development and the path to boost this type of project in the country has been through so-called "innovative" auctions. Nevertheless, according to the Association of the Energy and Water Industry (Bundesverband der Energie- und Wasserwirtschaft), even though such innovative auctions are on the right path to promote greater flexibility to the power system, changes are needed in the EEG for flexibility foster continued innovation (Appunn, 2020b).

Hybrid Auctions – India's Experience

In India, hybrid projects are predominantly composed of solar and wind sources due to the potential for complementarity of generation in same locations and between different regions of the country, with natural resources diversity.

India has enabled hybrid projects by means of customized auctions and has become an important benchmark to be considered by other countries sharing the same interests. Since 2018, the application of this type of energy contracting mechanism has resulted in relevant increase in the installed capacity of hybrid projects, expected to reach 5 GW by 2023.

This relevant achievement derived from a policy[2] of continuous promotion of customized auctions designed to overcome restrictions in the connection and transmission system and to meet the market demands, mainly, related to the need for less contractual risk in the energy supply. India has cases of customized auctions for meeting peak and "Round-The-Clock" electricity requirements of distribution companies (Discoms).

In the standard auctions for hybrid projects, to guarantee the solar-wind composition in the hybrid projects, avoiding purpose deviation, India uses the criteria of minimum participation of the sources in the composition. One of the criteria considered is that rated capacity of one source (wind/solar) must be at least 33% of the total contracted capacity of the Hybrid Project. The policy facilitates projects to be designed in such a manner which allows maximum participation of the source with highest local energy potential. In such auctions, the contracting modal is a standardized power purchase agreement (PPA).

At the auctions for meeting peak supply, contracts have two selling prices, one applied during peak hours (limited to 2 hours in the morning and 4 hours in the evening) and another applied during the off-peak periods. In addition, there is heavy contractual penalty if the generator does not deliver on his peak load supply commitment. In this type of auction, some hybrid projects also relied on storage systems in their composition.

The round-the-clock (RTC) contracting modal was used in an auction customized to the requirements of some utilities. One of the contractual rules establishes that the energy delivery must perform a minimum of 80% Capacity Utilization Factor (CUF) per year and at least 70% of the monthly CUF. Additional contractual clauses are: (i) prices with 3% annual escalation for 15 years, (ii) excess generation can be sold in open market, (iii) heavy penalty for not meeting requirements and (iv) multiple generation plants can compose total generation.

The concept of hybrid projects in India's auctions is also extended to multi-located projects, which consists of a portfolio of generation assets in different locations, aiming to optimize global resources. This important expansion in the concept of hybrid projects allows India to fully take advantage of complementarity of renewable resources from different regions of the country.

This is a relevant point to be considered. By allowing hybridization of different plants from different regions, India enables insolated project development that may not be economically feasible by themselves but may become feasible when associated with other projects from other regions when treated as hybrid. It means that by doing so, India allows complementarity to enable more investment in the generation expansion.

The country experienced a rapidly falling tariff[3] scenario (IRENA, 2019a), where multi-located projects showed lower tariffs than co-located projects. Nowadays, there are 1.440 MW (hybrid) plus 1.200 MW (Peak Power) being implemented under co-location mode, while 1.110 MW (hybrid) plus 400 MW (RTC) being implemented under multiple location mode.

India's experience brings up worthwhile discussions. The natural characteristic of solar peaks during the day and wind in the night results in intermittencies in supply impact grid resilience, making Discoms reluctant to buy power from standalone wind and solar projects. In case of hybrid, the two sources complement each other, overcoming the problems of variability of generation and grid security, and thereby Discoms' reluctance and allowing to leverage solar-wind complementarity. To pave the expansion of hybrid projects, regulatory adjustments have been made to address different issues, such as grid connection, power scheduling, project location, storage applications, among others. Regarding the projects composition, the trend is for an increase in the number of hybrid projects with the participation of storage systems. Hybrid projects with storage are capable of guarantee peak load generation, besides improving the Capacity Utilization Factor. Hence, these devices have the potential to reduce the country's dependence on gas and pumped hydro plants to meet peak load demand.

Hybrid power has been predominantly demanded by Discoms as part of their projected renewable energy expansion, in view of better demand management options and increased efficiency, resulting in efficient system operation. System operation planning and long-term

[2] The Ministry of New and Renewable Energy (MNRE) adopted the National Wind-Solar Hybrid Policy on 14 May 2018. The objective of the policy is to provide a framework for the promotion of large grid-connected wind-solar PV hybrid systems for efficient utilization of transmission infrastructure and land. For more on, see: Gulia & Garg (2020).

[3] In this text, as considered in the original bibliography researched, tariff is the price paid to the projects developers resulting from the public auctions.

expansion planning of renewable energy infrastructure is based on predicted increase in hybrid projects.

In addition, hybrid project designs enable utilities innovation at marginal costs under an observed rapidly falling tariff scenario.

Wind and Solar Auctions – Brazilian Experience

Brazil has a successful history of applying auctions as a mechanism to promote the expansion of renewable sources. The economic attractiveness of solar and wind projects was strongly boosted through the auctions adopted to provide electricity to the regulated Brazilian market. Nowadays, because of the rapid fall in the prices of wind and solar sources at auctions in Brazil, these technologies are at similar levels of competitiveness.

With falling energy prices in the auctions, it is important to highlight that the contracts offered in these auctions presented a gradual evolution with respect to risk allocation, which was guided by the evolution of the maturity of the sources.

Initially, the contracts offered in the auctions contained availability clauses, in which the generation risk was allocated to the buyers, that is, transferred to the Discoms and passed through to final consumers. With the increase of cost competitiveness of renewable sources, such risks have become contractually allocated to the sellers by means of the quantity contracts clauses, ensuring that the generator takes the risk by not fulfilling the supply commitment.

In this context, Brazil has relevant experience in using auctions for the insertion of different generation technologies. Such experience that serves as an important basis for regulatory and auction rule adjustments aiming to allow the isonomic participation of hybrid projects in the auctions.

Main issues to be addressed in combined wind and solar auctions.

A relevant question about auctions lies on the definition of the types of projects that will be eligible to participate in the procurement process. The first possibility adhering to the Brazilian reality would be the joint participation of solar and wind separated projects competing with hybrid projects in the same auction.

The participation of these three types of projects in a same auction would be justified by the fact that the solar and wind power plants reached similar levels of economic attractiveness. Therefore, the three types of plants could compete against each other, ensuring the technological neutrality as well as preventing market reserve.

In addition, it would allow project developers to incorporate the benefit of association or hybridization in their bids. Auction design shall consider wind, solar and wind-solar hybrid projects competition in the same bidding process.

In this context, it is important to highlight that there is space for both the installation of a new hybrid project (greenfield) and the hybridization of existing projects through the incorporation of a new source, making an associated project, according to EPE (2018) typification, which demands some regulatory adjustments due to the new entrant (for example, cutting generation, contracting the use of outlets, regulatory discounts, among others)[4].

The proposed alternative does not exclude the additional possibility of holding exclusive auctions for hybrid projects, due to specific objectives envisaged by the system planner. A relevant advantage to be highlighted about specific auctions, as in the India's example, is to eliminate local transmissions congestion by implementing local hybrid projects. This is a similar scenario experienced by the Brazilian Northeast region, where some projects alone may not be feasible due to the lack of transmission capability. However, it is important to observe that exclusive auctions for hybrid projects may result in poor competition among different technologies.

In these exclusive combined auctions, a minimum share of each source in the hybrid project could be required to ensure that the project is in fact hybrid, avoiding undesirable hybrid project composition that could represent cross-subsidy to be paid by the final customer with windfall profits to developers.

This definition can be challenging to set, since a low share may act as symbolic, and a high share may lead to non-optimum projects, depending on the local resources. Nevertheless, if the competition is entirely open, and the risks and cost allocations are well addressed, the requirement of minimum share may not be necessary.

The curtailment risk is inherent in hybrid and associated projects. The entrepreneur must bear the financial consequences of the eventual curtailment, which must include this effect in his project's feasibility strategy.

[4] Such issues were the subject of public discussions with the market promoted by the regulator (ANEEL) in late 2020 and early 2021. See CP-061/2020 and TS-011/2020 at: https://www.aneel.gov.br/consultas-publicas.

5. Regulatory Issues

Main regulatory framework adjustments for insertion of hybrid projects were subject to a recent public consultation process in Brazil, held in December 2020 by ANEEL through CP-061/2020.

Central discussions were focused on: (i) Facilitate granting and regulatory authorization of power plants with more than one source; (ii) Establish a form of contracting the transmission use by hybrid power plants; (iii) Enable the commercialization of the energy generated by hybrid, and (iv) Create alternatives for calculations of the Firm Generation Certificate for generating power plants with more than one source.

Regarding the definition of the Firm Generation Certificate for hybrid/associated projects: currently, individualized solar PV and wind have their firm generation defined based on simple statistical calculations, taking the 50^{th} and 90^{th} percentiles. For hydroelectric projects, on the other hand, the calculation procedure involves simulations of the interconnected system and is quite complex.

It is observed that the differentiation in the adoption of these criteria is due to the natural characteristics of each source (variability of production, for example), aiming to provide an estimate of generation to the entrepreneur to meet contractual commitments, in addition to serving as an indicator of planning and system operation.

One option for the calculation of firm energy credits is to consider the sum of the individual physical guarantees of the individual plants, reduced by the estimated amount of curtailment. This alternative presents itself as a low impact regulatory solution for its adoption in the short term and is adherent to EPE calculation proposal suggested in EPE (2020).

Regarding the rules for contracting the use of transmission networks for hybrid plants, it is necessary to make the current contracting criteria more flexible[5], to define the limit of power injection in the connection of hybrid/associated projects as being a range of the overall Installed Capacity, characterized by the value between the greatest Installed Capacity and the sum of the Capacity of all sources. Such flexibility will allow generators to optimize the contracting of the network use amount.

[5] The current criterion determines that the power plant must contract the equivalent of its nominal power.

6. Hybrid Projects Composed by Other Technologies

Countries such as Australia and India have significant capacity of hybrid projects combining solar photovoltaic and wind sources, due to the potential for local complementarity. However, in general, the international experience shows a predominant trend for combining hybrid projects with storage systems, mainly electrochemical batteries. This trend is mainly associated with a low potential for local complementarity of generation sources.

The combination of hybrid projects with storage systems relies on reducing the variability of the generation profile of renewable uncontrollable sources, thus allowing better use of the connection system, greater operational flexibility and better contract management. Countries such as the USA, Australia, and some European Union Member States have stood out with the expansion of these projects´ arrangements.

Additionally, other technology combinations can also be considered as alternatives for hybrid projects. For example, hydroelectric or thermoelectric (including biomass) plants combined with photovoltaic, wind, batteries, or hydrogen storage.

Such combinations can ensure profitability of these assets by allowing developers to take advantage of more flexibility in the operation of power plants, in terms of capacity value, dispatchability, ancillary services, and reliability (NREL, 2020).

In Australia, approximately 2.08 GW of the 3.4 GW of hybrid projects total installed capacity are represented by combinations of solar and wind sources combined with battery systems (Clean Energy Council, 2020).

Storage systems expanded so rapidly that in September 2020 the Australian regulatory agency (Australian Energy Market Commission - AEMC) opened a public hearing seeking for clear rules to be applied for battery systems installed standalone or combined with generation sources, thus composing hybrid projects, as combination of a source of generation with a storage system is considered a hybrid project. Discussions on the market operator registration, participation in electricity and ancillary service markets, the definition of charges and taxes, and the use of distribution and transmission systems took place during the hearing (AEMC, 2020).

The main AEMO's public hearing proposal was to create definitions within the regulation for hybrid projects and storage systems. Under the current regulatory context, these agents need to be registered for dispatch and accounting purposes both as load and generation entities, as storage systems can consume or inject relevant amounts of energy into the system's network. AEMO says that this issue is also faced by hybrid projects which have consumption and generation assets behind the same network connection, even if there is no storage unit combined.

In AEMO (2019a), the operator argues that creating a definition for bidirectional units would not only solve the problems faced by investors when registering the project, but also by simplifying rules for centralized dispatch participation. The current market rule demands the hybrid project or the storage facility to offer two bids for the market, one for the consumption part and another for the generation part. Proposed rules will also clarify the charges and taxes to be applied.

The United States is another country with relevant amounts of storage systems installed. By the end of 2019, 53 out of 125 hybrid projects in operation combined photovoltaic or wind source with storage systems (Wiser et al., 2020).

In addition to most traditional configurations, the country has other models of hybrid projects in operation. These combine hydroelectric, thermoelectric, biomass, and geothermal energy. Table 1 describes the hybrid projects in operation in the USA by the end of 2019. *Gen 1*, *Gen 2*, and *Gen 3* stand for the capacity in MW of each source according to specified order in the first column. For example, the second line shows that there are two projects in the country combining wind, photovoltaic, and storage, summing up 216 MW of wind, 21 MW of solar and 34 MW of storage.

Table 1 – Hybrid projects in the USA by the end of 2019. Source: Wiser et al. (2020)

Installed at end of 2019	# projects	Gen 1 (MW)	Gen 2 (MW)	Gen 3 (MW)	Total Gen (MW)	Storage capacity (MW)	Storage energy (MWh)	Storage: generator ratio	Duration (h)
Wind + Storage	13	1,290	0	0	1,290	184	109	14%	0.6
Wind + PV + Storage	2	216	21	0	237	34	15	15%	0.4
Wind + Fossil + Storage	1	5	12	0	17	1	1	7%	0.8
Wind + PV + Fossil + Storage	1	0.1	0.1	1	1	0	1	25%	1.7
Wind + PV	6	535	212	0	747	0	0	0%	n/a
Wind + PV + Fossil	3	6	2	98	106	0	0	0%	n/a
Wind + Fossil	8	27	79	0	106	0	0	0%	n/a
PV + Storage	40	882	0	0	882	169	446	19%	2.6
PV + Fossil	26	77	6,876	0	6,953	0	0	0%	n/a
PV + Fossil + Storage	3	9	10	0	20	5	9	24%	1.9
PV + Biomass	3	4	15	0	19	0	0	0%	n/a
PV + Geothermal	2	18	85	0	103	0	0	0%	n/a
PV + Geothermal + CSP	1	22	47	2	71	0	0	0%	n/a
CSP + Storage	2	390	0	0	390	390	2,780	100%	7.1
Fossil + Storage	10	2,414	0	0	2,414	91	84	4%	0.9
Hydro + Storage	4	71	0	0	71	12	11	17%	0.9

By July 2020, considering the relevant expansion of hybrid projects in the USA, the American (US) regulatory agency (Federal Energy Regulatory Commission - FERC) promoted a conference, called "*Technical Conference Regarding Hybrid Resources*".

During the event, different types of stakeholders discussed changes in regulation and market rules that should be addressed. The California Independent System Operator (CAISO), PJM Interconnection, Midcontinent Independent System Operator (MISO) and ISO-NE Interconnection also participated in the conference (FERC, 2020), where it was shown that most hybrid projects in operation or under construction in the USA are represented by the combination of a solar and/or a wind plant with batteries.

Conference discussions focused on (i) how network connections should be defined, (ii) the numbers of meters needed, (iii) how the studies and connection process should be carried out, (iv) how to define outflow limits, (v) if responsibilities regarding project coordination should be assigned to the project or to the system operator, (vi) how the battery should be charged and discharged, and (vii) how the participation in the energy, capacity, and ancillary services markets should take place.

China holds incentives to combine renewable energy sources with storage. Eighteen of its provinces have policies to encourage storage systems. Some of these even establish guidelines for new wind projects to be hybridized with storage systems, to reduce the curtailment of intermittent sources (Zhang et al., 2020).

In August 2020, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA), both of which are regulatory bodies in China, published a technical document entitled "*Guideline on Wind-Solar- Hydro-Thermal Integration and Generation-Grid-Load-Storage Integration Development*".

The document proposed three possibilities for combining production sources and storage on the generation side: (i) solar, wind, thermoelectric and storage; (ii) solar, wind, hydroelectric, and storage; and (iii) solar, wind and storage systems. The document also states that changes must be implemented in the ancillary services mechanism, to allow frequency modulation and peak-demand to be delivered by hybrid projects (NDRC & NEA, 2020).

In August 2019, India held its first auction with the obligation of adding storage to hybrid projects. The auction required the storage capacity to be at least "X/2 MWh", where "X" represents the project's capacity procured. Project's winners, Greenko (capacity procured of 900 MW) and ReNew Power (capacity procured of 300 MW) shall invest in pumped-up storage and batteries (Gulia & Garg, 2020).

The contract negotiated in this auction also contained a different approach to pricing. Two prices were used, one for peak hours and another for off-peak hours. This led to the tender being called the peak power supply auction. The tariff for off-peak hours has been specified as ₹ 2.70 (~ $0.03) /kWh and for peak hours it shall be defined in e-reverse auctions to be carried out in real-time (Mercom India, 2020).

European countries such as the Netherlands, Spain, Poland, and Greece have developed Research and Development pilot projects combining, in most cases, wind and solar generation with batteries. In a more advanced stage, Portugal and Germany held auctions for projects combining renewables with storage.

The United Kingdom, shortly after leaving the European Union, has shown an interest in more rapidly expanding the participation of storage resources in its electrical system. Recent unofficial proposals have been discussed for combined project models with existing renewables, which can add storage and maintain subsidies (Ofgem, 2020).

Due to a more stable generation profile when coupling batteries to renewable generation sources, some countries such as Australia and the independent operators in the USA, CAISO, PJM, and ISO-NE, allow the provision of ancillary services by these hybrid compositions.

In Brazil, besides regional and locational complementarity between solar and wind sources, R&D[6] studies were carried out with optimization models for individualized simulation of hydroelectric power plants associated with other generation sources or technologies. The results were encouraging, when considering a hydroelectric power plant combined with solar and a set of batteries including hydrogen storage.

Moreover, the expansion of hybrid projects in the Brazilian Interconnected System could be driven by the electricity market design modernization due to proposals of creating capacity-like mechanisms and an ancillary services market. Therefore, the procurement of ancillary services should allow standalone generation projects and hybrid projects with storage to participate is this new market as well.

To provide advances in the regulatory framework related to electricity storage, ANEEL asked for contributions by publishing the TS011 (“Tomada de Subsídios – TS011/2020”). A comprehensive treatment of the theme can be found in the technical report produced by the Regulator for TS011(ANEEL, 2020).

[6] Project developed on P&D Furnas PD 00394-1606/2016. “Desenvolvimento de Sinergia entre as Fontes Hidrelétrica e Solar com Armazenamento de Energias Sazonais e Intermitentes em Sistemas a Hidrogênio e Eletroquímico (SHSBH2)”. For more details on the project please see Balan et al. (2019).

7. Operation and Planning System Perspectives

The potential of a hybrid power plant depends not only on the resources and costs, but also on the market structure to which it belongs. These characteristics determine what types of revenue streams are available to which type of assets. For instance, revenues can be originated from capacity markets, energy markets and ancillary service markets (NREL, 2020).

Regarding the operation of hybrid projects in energy markets, there are the examples of independent operators as CAISO, PJM, and ISO-NE from the USA, that consider two configurations of hybrid projects: the "co-located" and hybrid resources.

Co-located projects are two or more generation technologies, with or without the presence of storage systems, that share the same physical connection with the network but represent independent agents for dispatch purposes, control, and contractual obligations. Hybrid resources, on the other hand, are projects represented by a single agent in the market, which shares control of dispatch and generation, carried out by a single operator, jointly between the project's components (FERC, 2020).

CAISO's understanding on hybrid resource configuration is that storage systems can be used to reduce the intermittent characteristics of renewable sources, and it is the responsibility of the project owner to coordinate the generation between the different components of the facilities. CAISO operates the dispatch of hybrid resources in the same way as non-intermittent generation systems, according to the reported bids.

CAISO (2020) states that flexibility permitted to the project owner in managing the operation between components brings about benefits concerning (i) in the fulfillment of the contractual obligations, (ii) in tariff incentives, and (iii) in the project's operation and maintenance expenses.

In the case of co-located projects, CAISO understands that dispatch must be coordinated by the market operator. This model facilitates the segregation and fulfillment of contractual responsibilities between the different components of the project.

At a conference held by FERC, PJM emphasized that, when the storage system is part of a hybrid project, the operation management must be carried out by the project operator and not by the system operator, due to the better knowledge of the project's operator on the current generation and provision of the renewable source and storage. On the other hand, for co-located projects, where resources are represented by different and independent market participants, the dispatch and operation must be carried out by the system operator to avoid unfeasible dispatch orders (PJM Interconnection, 2020).

CAISO, PJM, and ISO-NE operators allow hybrid projects to participate in energy, capacity, and ancillary services markets, under both co-located and hybrid resource configurations. However, the ISO-NE operator advises that hybrid projects combining renewables and storage should participate in the ancillary services market as a hybrid resource, so the project owner may manage generation and storage with more coordination and efficiency (ISO New England Inc, 2020).

In July 2019, Australia's AEMO (2019b) issued a document containing guidelines on various configurations of hybrid projects that could be established within the current regulation.

In the first set of configurations, it is not possible to distinguish generation and load between different components of the project, therefore the entire hybrid project is represented by a single market agent for accounting and dispatch. In the second set, there are multiple meters behind the meter connected to the network, and the system components are represented by independent agents for accounting and dispatch purposes (in this case the project only shares the local infrastructure and physical network connection).

Regarding the coordination between project's components for dispatch when it is not possible to identify the generation between different components and there is only one meter connected to the network, the understanding is that the coordination management between components must be carried out by the project owner.

Current Australian market design allows hybrid projects to participate in the energy and ancillary service markets. However, as these projects may both consume or inject energy into the network (when combined with storage), the system operator applies both registration and dispatch rules established for generation and load agents, which according to current regulation, cannot be aggregated for dispatch in the energy and ancillary service markets.

Expansion planning is becoming increasingly relevant for electrical systems as the energy transition to a low carbon economy provides greater penetration of variable and decentralized energy resources. Consequently, operational flexibility has become an important role in many electricity markets around the world.

Recent discussions propose the reformulation of capacity mechanisms to consider flexible attributes such as ramp capability and duration of discharge (IRENA, 2019b) and in different markets, evolutions are observed to allow new and more flexible technologies to participate, including hybrid projects, batteries, demand response, storage of hydrogen and biogas, and interconnections. Ideally, such flexible attributes and resources should also be considered in the expansion planning methodologies.

In Brazil, expansion planning is carried out annually, with ten-year plans developed by the Energy Research Office (EPE). The methodology essentially uses two optimization models, NEWAVE and the Investment Decision Model (MDI). Both models complement each other in the analysis of long-term electrical and energy balance, minimizing the marginal cost of the operation until the end of the simulated horizon, for which MDI suggests an ideal expansion considering the investment and operation costs of each type of generation resource.

Besides the traditional water storage in hydroelectric plant reservoirs, MDI also considers, for expansion purposes, investment in batteries and pumped-storage hydro plants, therefore already incorporating new, more flexible technologies in the process, despite not yet considering a combination of technologies in a single hybrid project. Transmission costs are also considered in the analysis and, as result, these assets will serve as key elements for optimizing the operation and meeting the future system needs, including flexibility.

Considering the expansion planning process, and not only the MDI formulations, the promotion of changes to accommodate hybrid resources would be an interesting way to encourage the expansion of new technologies in Brazil. For example, it is possible to incorporate the value of flexible attributes, since hybrid projects combined with storage can bring important contribution to a faster ramp, for instance as well as synthetic inertia or even conventional hydro and thermal power plants.

In Brazil, transmission assets are not market participants. As regulated agents, transmission agents get their remuneration for ensuring that their assets are available to the system operator. Therefore, regarding the contribution of interconnections, the aggregated expansion planning of generation, storage and transmission would be an approach to optimize the contribution of interconnections to flexibility.

Thus, the benefits of local flexibility could be considered, and the mitigation of systemic curtailment could be locally optimized. The example of PJM’s Reliability Pricing Model, or PJM’s capacity market, which makes locational analyzes based on transmission system restrictions is a good example (PJM Interconnection, 2021).

Considering Brazil's extension and the different types of energy supply installed in each location, the expansion planning formulations should take place through more detailed and regionalized electrical studies, to optimize the participation of hybrid projects internally to the submarkets.

The planning should also consider price granularity on an hourly basis, which would provide important reductions in price volatility and would also improve investment signals. In EPE transmission planning studies, detailed electrical studies are held. But for planning interests (PDE – Decennial Expansion Plan)[7], it is an indicative approach.

The PDE objective is not to define how much (and where) of each source should we have, but to identify the system needs in the next years and scenarios for how these needs can be met. And, based on these findings, it helps to pave the way for a reliable system.

From the system expansion planning perspective, transmission competes directly with other technologies to provide flexibility. In the case of India, for example, transmission restrictions between provinces were the incentive for hybrid project auctions. Therefore, the participation of transmission as a possible solution to address issues on flexibility makes it even more relevant to include hybrid projects into the expansion planning optimization.

Brazilian market design has discussed relevant modernization process with a focus on more market liberalization. As most of the generation expansion has been carried out centrally through a regulated environment, the government proposes the creation of a capacity-like mechanism to foster the system's resource adequacy, since the regulated market is reducing its participation on the total share of the expansion.

However, for the expansion of modernization to be optimized and to encourage the participation of hybrid projects and storage resources, it is important to value flexibility as an operational attribute of the sources. Electricity markets in Alberta, California and PJM are examples of capacity mechanisms considering flexible requirements. Regarding the participation of hybrid projects, in the PJM area, projects with different generation resources or technologies and with a capacity above 100 kW can participate jointly (as a single participant) in the capacity market (PJM Interconnection, 2020).

[7] https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-decenal-de-expansao-de-energia-pde

In addition, the study of (NREL, 2020) reveals that in predominantly hydraulic markets, with storage reservoirs, the systematic operational and support benefits (flexibility) promoted by hybrid plants are less perceived by the system. In this case, it is important to note that such evidence should not be interpreted as the absence of local and/or even systemic benefits.

Another point of attention regarding system planning in Brazil concerns the Firm Energy Certificate (FEC). The FEC limits the energy amount that power plants can sell, based on their contribution to the system's electro-energetic balance in times of hydrological crisis. Therefore, the FEC of each project assists adequacy studies, directly influencing the expansion planning.

Under current regulatory framework, the calculation of the FEC for wind and solar parks, recognizes a limited amount of energy supply to the system due to the variability of production, because current methodology considers that only a percentage of the energy production should be considered as firm.

Improvements in FEC's methodology, especially when considering the association of complementary sources such as solar, storage, and wind in a hybrid project could foster the expansion of these sources in the national scenario. Hybrid projects can offer a more predictable and stable volume of energy to the system. Also, when combined with storage, the energy supply recognized in the system may be even greater due to the reduction of curtailment and to the power plant dispatchability.

Recently, EPE issued the technical note NT-EPE-DEE-084-2020 (EPE, 2020), proposing initial considerations to the calculation of FEC for wind-photovoltaic associated plants to consider a reduction factor resulting from the expected curtailment.

From the investors' perspective, the suggested rule implies the agent cost-benefit evaluation between storage investment versus (i) the changes in the FEC and (ii) its consequences on the project electricity outflow. The document did not address the issue of the FEC's methodology to hybrid projects, including other sources, which is still an issue to be addressed and will demand deeper studies and debates among all the stakeholders.

8. Conclusions and Recommendations

The 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.

Even though hybrid projects represent a new technological domain in Germany, especially the combined wind and solar plants, the country is a good example on how to successfully adopt public auctions to contract these plants. In 2020, Germany held a so-called "innovative auction" in which hybrid projects were eligible to participation for the first time. The auction contracted 394 MW in hybrid projects (mainly solar-storage combination).

In 2021, two new auctions are planned to be held exclusively for hybrid projects, with a target of contracting additional 250 MW. Although this is a recent movement in the electricity industry of the country, Germany is an important example of a country in which the expansion of hybrid projects tends to occur quickly and through specific auctions, since the country has set the target of 65% in renewable electricity generation by 2030, which is quite representative.

Considering the experience of India with combined wind-solar auctions that have been held since 2018, several benefits of this arrangement are pointed, such as a more efficient transmission system and a better use of land to implement projects with generation variability reduction. There have been combined auctions with renewables even for peak load and run of the clock electricity supply held already.

In India, where natural resources are spread across the country's vast territorial area, hybrid projects entail several benefits. In addition to traditional “co-located” hybrid projects, there are also the “multi-located” projects that can enable the development of plants that would not be economically feasible if isolated.

In Brazil, because of the relevant presence of Hydro Power Plants, it is of particular interest to consider hybridization of hydro plants with other renewable generation such as wind and solar plants, considering or not storage. This issue should be the object of a specific further study.

To prevent pre-defined technological market quotas, cross subsidies and windfall profits, auctions ought to allow hybrid and individual projects to compete in the same process. In this way, if hybridization does not lead to relevant increase in competitiveness, the auction design is prepared to select the individual projects, as they are more competitive.

In this case a tight regulation is essential to pre-qualify projects, to make sure that the projects allowed to participate in the auction, either brownfield or greenfield, are baked up by developers with experience and technical/financial capability. It is also important to issue effective rules to ensure that the characteristics of the project effectively implemented match those of the project that was submitted to habilitation before the auction.

In Brazil, what is important for regulation is that the project meets, at least, what was contracted in the auction: amount of energy contracted on the established period, and other basic features, irrespectively of whether the project is individual or hybrid. There are several alternatives to provide these guarantees. On the other hand, it is also relevant to minimize financial risks to developers by providing guarantees of the contracted electricity payment.

The stricter the habilitation rules and the enforcement of contractual obligations, the slimmer are the chances of materialization of the so-called “Winner's curse”, in which project implementation delays or underperformance leads to the “Off-taker's nightmare”. Thus, it may not be relevant to require a certain proportion of each source in the hybrid project, or to require that a storage system is associated or not – as long as the contractual obligations are fully enforced and delivered by the plant. This is, in fact, what shall be tightly regulated.

Finally, regulation, system operation and expansion planning must be adapted to the introduction of combined projects into power systems. The main regulatory topics to be addressed relate to transmission contracting and the characterization of hybrid projects, as discussed in ANEEL CP061/2020.

From the operation standpoint, it is relevant for centralized operation to recognize and consider local characteristics of hybrid projects. And, expansion planning must consider the specific needs of the system in terms of adequacy and reliability, as well as the attributes of the sources and technologies composing the expansion plan.

References

AEMC. (2020). *Australian Energy Market Commission*. Retrieved October 09, 2020, from CONSULTATION PAPER - NATIONAL ELECTRICITY AMENDMENT (INTEGRATING ENERGY STORAGE SYSTEMS INTO THE NEM) RULE: https://www.aemc.gov.au/sites/default/files/documents/consultation_paper_-_integrating_ess_into_the_nem_17082020_for_upload.pdf

AEMO. (2019a). *Australian Energy Market Operator*. Retrieved October 09, 2020, from ELECTRICITY RULE CHANGE PROPOSAL INTEGRATING ENERGY STORAGE SYSTEMS INTO THE NEM: https://aemo.com.au/-/media/files/electricity/nem/initiatives/emerging-generation/23-august-2019--integrating-ess-rule-change-proposal-final.pdf

AEMO. (2019b). *Australian Energy Market Operator*. Retrieved October 09, 2020, from Registering a Hybrid Generating System in the NEM: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Participant_Information/New-Participants/Fact-Sheet--NEM--Hybrid-Generator-Registration.pdf

ANEEL. (2020). *Nota Técnica nº 094/2020-SRG/ANEEL.* Retrieved from https://www.aneel.gov.br/tomadas-de-subsidios?p_p_id=participacaopublica_WAR_participacaopublicaportlet&p_p_lifecycle=2&p_p_state=normal&p_p_mode=view&p_p_cacheability=cacheLevelPage&p_p_col_id=column-2&p_p_col_count=1&_participacaopublica_WAR_participaca

Appunn, K. (2020a, September 23). *German cabinet approves renewables reform, but parliamentarians eye changes.* Clean Energy Wire. Retrieved from Clean Energy Wire: https://www.cleanenergywire.org/news/german-cabinet-approves-renewables-reform-parliamentarians-eye-changes

Appunn, K. (2020b, October 1). *Solar, storage hybrid projects win majority of Germany's new "innovation auctions.* Retrieved from Clean Energy Wire: https://www.cleanenergywire.org/news/solar-storage-hybrid-projects-win-majority-germanys-new-innovation-auctions

Bagatini, M., Benevit, M. G., Beluco, A., & Risso, A. (2017). Complementarity in Time between Hydro, Wind and Solar Energy Resources in the State of Rio Grande do Sul, in Southern Brazil. *Energy and Power Engineering*, 515-526.

Balan, M. H., Ramos, D. S., Camargo, L. A., Lopes, M. M., & Guarnier, E. (2019). Modelo de Otimização da Operação de Usinas Hidrelétricas Individualizadas associadas a usinas fotovoltaica, termosolar e eólicas. *XXV SNPTEE SEMINÁRIO NACIONAL DE PRODUÇÃO E TRANSMISSÃO DE ENERGIA ELÉTRICA.* Belo Horizonte.

Bundesnetzagentur. (2021a, March 23). *Innovation calls / bid date 1 April 2021.* Retrieved from Bundesnetzagentur: https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Ausschreibungen/Innovation/Gebotstermin010421/Innov_010421_node.html

Bundesnetzagentur. (2021b, March 23). *Tender procedure.* Retrieved from Bundesnetzagentur: https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Ausschreibungen/Innovation/Ausschreibungsverfahren/AusschrVerfahren_Innov_node.html

CAISO. (2020). *FERC Technical Conference on Hybrid Resources - TECHNICAL CONFERENCE COMMENTS OF THE THE CALIFORNIA INDEPENDENT SYSTEM OPERATOR CORPORATION.* CAISO, California Independent System Operator (CAISO).

Camargo, L. A., Leonel, L. D., Ramos, D. S., & Stucchi, A. G. (2020). A Risk Averse Stochastic Optimization Model for Wind Power Plants Portfolio Selection. *2020 International Conference on Smart Energy Systems and Technologies (SEST)*, (pp. 1-6). Istanbul, Turkey.

Campos, R. A., Nascimento, L. R., & Rüther, R. (2020). The complementary nature between wind and photovoltaic generation in Brazil and the role of energy storage in utility-scale hybrid power plants. *Energy Conversion and Management*, 113160.

Cantão, M. P., Bessa, M. R., Bettega, R., Detzel, D. H., & Lima, J. M. (2017). Evaluation of hydro-wind complementarity in the Brazilian territory by means of correlation maps. *Renewable Energy*, 1215-1225.

Clean Energy Council. (2020). *Project-Tracker*. Retrieved December 11, 2020, from https://www.cleanenergycouncil.org.au/resources/project-tracker

Dierks, S. (2020, September 30). *Erste Innovationsausschreibung Deutlich Überzeichnet.* Retrieved from Energate Messenger: https://www.energate-messenger.de/news/205936/erste-innovationsausschreibung-deutlich-ueberzeichnet

EPE. (2016). *Energia Renovável: Hidráulica, Biomassa, Eólica, Solar, Oceânica.* Rio de Janeiro: Empresa de Pesquisa Energética (EPE) / Mauricio Tiomno Tolmasquim (coord.).

EPE. (2017). *Avaliação da Geração de Usinas Híbridas Eólico-Fotovoltaicas: Proposta metodológica e estudos de caso.* Nota Técnica, EPE, Rio de Janeiro. Retrieved from http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-232/topico-214/Metodologia%20para%20avalia%C3%A7%C3%A3o%20de%20usinas%20h%C3%ADbridas%20e%C3%B3lico-fotovoltaicas.pdf

EPE. (2018). *Usinas Híbridas: Uma análise qualitativa de temas regulatórios e comerciais relevantes ao planejamento.* Nota Técnica, EPE, Rio de Janeiro. Retrieved from http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-232/topico-393/NT%20EPE-DEE-NT-011-2018-r0%20(Usinas%20h%C3%ADbridas).pdf

EPE. (2020). *EPE-DEE-NT-084/2020-r0: Usinas associadas eólico-fotovoltaicas - Considerações para cálculo de garantia física de energia.* Rio de Janeiro – RJ: Empresa de Pesquisa Energética.

European Commission. (2018). *Battery Promoting Policies in Selected Member States.* European Commission, Bruxelas.

Fant, C. S., Schlosser, C. A., & Strzepek, K. (2016). The impact of climate change on wind and solar resources in southern Africa. *Applied Energy, 161*, 556-564.

FERC. (2020). *Technical Conference regarding Hybrid Resources (Docket No. AD20-9-000).*

GIZ & MME. (2020). *Estudo climático: Análise da Vulnerabilidade de Usinas Hidrelétricas aos Impactos das Mudanças Climáticas.* MRTS Consultoria, Brasília.

Gulia, J. & Garg, V. (2020). *Wind-Solar Hybrid: India's Next Wave of Renewable Energy Growth - An Analysis of Tariff Trends, Policy and Regulation, and Challenges in a New Market.* JMK Research & IEEFA Energy Economist.

IRENA. (2019a). *Renewable Energy Auctions: Status and trends beyond price.* International Renewable Energy Agency. Abu Dhabi: www.irena.org

IRENA. (2019b). *Redesigning Capacity Markets - Innovation Landscape Brief.* International Renewable Energy Agency.

ISO New England Inc. (2020). *FERC Technical Conference on Hybrid Resources - Post-Technical Conference Comments of ISO New England Inc.* ISO New England Inc.

Mercom India. (2020, January 23). *SECI's Solar-Wind Storage Tender with Assured Peak Power Supply Oversubscribed by 420 MW*. Retrieved from Mercom India: https://mercomindia.com/seci-solar-wind-storage-peak-power-supply-oversubscribed/

Molnár, P., & Camargo, L. A. (2015). Applying Copulas Functions for Wind and Hydro Complementarity Evaluation: a Brazilian Case. *12th International Conference on the European Energy Market (EEM).* Lisbon, Portugal.

NDRC & NEA. (2020). *Guideline on Wind-Solar-Hydro-Thermal Integration and Generation-Grid-Load-Storage Integration Development*. Retrieved March 02, 2021, from China Energy Portal: https://chinaenergyportal.org/en/guiding-opinions-on-the-development-of-integrated-of-wind-solar-hydro-thermal-and-storage-integrated-of-generation-grid-load-and-storage-draft-for-comments/

Neto, D. A., Domingues, E. G., Coimbra, A. P., Almeida, A. T., Alves, A. J., & Calixto, W. P. (2017). Portfolio optimization of renewable energy assets: Hydro, wind, and photovoltaic energy in the regulated market in Brazil. *Energy Economics*, 238–250.

NREL. (2020). *Opportunities for Research and Development of Hybrid Power Plants.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-75026. Retrieved from https://www.nrel.gov/docs/fy20osti/75026.pdf

Ofgem. (2020). *Guidance for generators: Co-location of electricity storage facilities with renewable generation supported under the Renewables Obligation or Feed-in Tariff schemes.* Ofgem, Londres.

ONS. (2018). *NT 0016/2018. LEN A-4/2018: Quantitativos da Capacidade Remanescente do SIN para Escoamento de Geração pela Rede Básica, DIT e ICG.* Operador Nacional do Sistema. Retrieved from http://www.ons.org.br/AcervoDigitalDocumentosEPublicacoes/NT_0013-ONS-2020_%20LEE-A-4.pdf

PJM Interconnection. (2020). *FERC Technical Conference on Hybrid Resources – Panel III - Comments of Andrew Levitt, Senior Market Design Specialist, on behalf of PJM Interconnection.* PJM Interconnection.

PJM Interconnection. (2021). *Capacity Market (RPM).* Retrieved from PJM Interconnection: https://learn.pjm.com/three-priorities/buying-and-selling-energy/capacity-markets.aspx

USAID. (2019). *DESIGNING RENEWABLE ENERGY AUCTIONS: A POLICYMAKER'S GUIDE - Scaling Up Renewable Energy Project.* US Agency for International Development - - Energy and Infrastructure Office, Washington, DC. Retrieved from www.usaid.gov

Velloso, M. F., Martins, F. R., & Pereira, E. B. (2019). Case study for hybrid power generation combining hydro- and photovoltaic energy resources in the Brazilian semiarid region. *Clean Technologies and Environmental Policy*.

Wiser, R. H., Bolinger, M., Gorman, W., Rand, J., Jeong, S., Seel, J., . . . Paulos, B. (2020). *Hybrid Power Plants: Status of Installed and Proposed Projects.* Lawrence Berkeley National Laboratory.

Zhang, T., Cao, S., Pan, L., & Zhou, C. (2020). A Policy Effect Analysis of China's Energy Storage Development Based on a Multi-Agent Evolutionary Game Model. *Energies, 13*, 62-93.

www.bmwi.de