**Value Factor of Wind Generation in Brazil - Evolution and Prospects**

**Selected AB3E PAPER - BRAZIL**

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## Overview

The expansion of power systems through vertically integrated monopolies and the predominance of dispatchable (controllable) generation sources has disseminated the relevance of costs in the industry as a comparative metric to guide investments and justify public policies. It is recurrent the notion, even among policy makers, that a given generation source is competitive when its levelized cost of electricity (LCOE) becomes lower than the average electricity price or the average tariff of a specific region (grid parity). The consequence of the restricted view of costs is manifested in statements such as “the solar source is already more competitive than coal”, guiding the logic of policies aimed at the dissemination of variable renewable energy (ERV).

From this perspective, the analyzes that seek only to prove the physical viability of a power system dominated by ERV tend to neglect the evolution of marginal value of sources (FINON, 2016). This bias is also present in studies that only identify positive externalities, stacking attributes that are valued in terms of avoided opportunity costs consdiered as hidden benefits commonly negleted (BROWN, 2016). Likewise, the analyzes that only compute integration costs related to ERV variability also disregard the future evolution of power systems and its adaptation (MILLIGAN et al., 2011; HIRTH et al., 2015). Thus, there is a lack of economic rationality in these analyzes, since externalities are not internalized via neutral pricing mechanisms capable of signaling the effective costs and benefits of existing and potential resources.

In several countries, the initial penetration of ERVs was stimulated through public policies and specific regulation, rewarding investments in new installed capacity or generation. The use of feed-in tariffs, with fixed payments for each MWh, predominated in the European Union. In the United States, on the other hand, there is a predominance of generation credits (Production Tax Credit) at the federal level and renewable portfolios (Renewable Portfolio Standard) at the state level, determining the purchase by utilities of minimum quantity of renewable energy. These mechanisms encouraged the introduction of ERV at an early stage of development with high costs, in the context of mature power systems with a low expansion rate. However, as noted by Schmalensee (2016), these mechanisms are not sensitive to the variability of sources, without subjecting the premiums to the time and location of the energy generated, that is, without paying attention to the different marginal values ​​of the energy produced.

The systemic value literature of electricity sources recognizes that the role of ERVs and the diffusion of electricity markets converge to a new paradigm in the industry, imposing the transition from costs to value in order to avoid analyzes that reinforce subsidies via specific internalization or that neglect short and long term systemic gains (GRUBB, 1991; JOSKOW, 2011; UECKERDT et al., 2013; EDENHOFER et al., 2013; HIRTH, 2013; HIRT et al., 2016; IEA, 2014 and 2016; Romeiro et al., 2020). To compute the costs and benefits of electricity sources, the analyzes have to take into account the marginal value of electricity sources and its evolution, computing specificities of each system.

The “value factor”, the ratio between the source-weighted average electricity price and the load-weighted average electricity price, is one of the instruments used to infer the integration costs and their evolution over time. The premium or discount under the average price is determined by the degree of source penetration (market share) and is conditioned by the characteristics of the systems. The value factor has the advantages of (i) not requiring explicit cost decomposition; (ii) does not imply additivity of the components; (iii) allow the analysis of the time evolution of both past and projected costs; and (iv) allow the comparison between different systems, since the ratio expressed by the value factor is dimensionless, translating into a relative price.

In Brazil, the penetration of wind in the matrix, which already exceeds 14 GW of installed capacity, was stimulated mainly by its seasonal complementarity to the predominant hydropower generation, with greater generation during the dry period. In this sense, the contracting (PPAs) in centralized auctions took into account the long-term variability of the water regime, given that the regularization of reservoirs shifts the uncertainty of hydrological availability to the medium and long term. In this context, the contracting of wind power does not consider the hourly generation profile, only internalizing the value of medium and long term seasonality.

In order to maximize synergies among energy sources, the power dispatch in Brazil is performed centrally by the Brazilian Power System Operator (ONS). From the use of optimization models, ONS attempts to minimize the total cost of supply by deciding whether to use reservoir water now or to store it for the future. The solution for this intertemporal problem results in determination of the week-ahead operation marginal costs (OMC), for each four subsystems and daily level of load (light, medium and heavy). The OMC ultimately expresses the opportunity cost of water retained in the water reservoirs, that is, the shadow price of electricity in Brazil. For commercial purposes, the CMO is limited by minimum and maximum values, determining the settlement price of differences (PLD), used to settle short-term differences between previously contracted and effectively realized flows. Since April 2018, the ONS has preliminarily published the hourly OMC to turn the operation schedule on an hourly basis by 2020.

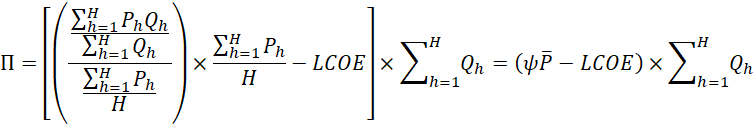
Brazil has set a Benefit-Cost Index (BCI) to compare the different sources in centralized power expansion auctions. The BCI compares the technologies that compete for availability contracts, ranking them in terms of expected benefit-cost. The BCI considers the generating alternatives from the point of view of buyer pool formed by distribution companies, valued for a 5-year future operation. The calculation is made from two thousand series of simulated hydrological scenarios, for each subsystem, which result in two thousand monthly equiprobable values for the future OMC. The ICB contains a cost component that captures the systemic benefit of the source. The CEC component (short-term expected economic costs) calculates the expected energy contribution of the source, in relation to its physical guarantee (expected annual average energy contribution, ie. the expected value of its firm energy), assessed by the PLD, for each of the two thousand monthly scenarios.

However, the Brazilian system is undergoing a profound transformation, due to the gradual and structural loss of regularization of the reservoirs, the difficulty of hydroelectric expansion, the penetration of variable renewable sources (wind, run-of-river hydroelectric, solar), the expansion of average and maximum demand and the change of its seasonal and hourly profile. The transformations alter the marginal value of energy in Brazil, requiring greater space-time granularity capable of reflecting the growing importance of medium and short term variability in the system. In this sense, the sector has already reviewed the distribution of daily load levels, with a longer duration of heavy load; intends to adopt marginal hourly operating costs from 2021, affecting the operation and the settlement of contractual differences; and discusses the transition from the model to offering agents' prices.

The objective of the article is to investigate the value factor of wind power in Brazil from hourly generation data effectively observed between 2015 and 2018, obtained exclusively, and average monthly hourly generation data between 2010 and 2018. The analysis considered the operation marginal costs of the Northeast and South subsystems for its daily load levels. It is also intended to investigate the impact of recent changes in the initial response to ongoing changes in the system: (i) the change in the duration of the load levels; and (ii) the use of semi-hourly OMC.

## Methods

The value factor can be calculated based on observed prices (backwarding-looking perspective) or based on projected prices (forward-looking perspective). In addition, the calculation can be made from observable market prices (Schmalensee, 2016) or shadow prices (Lamont, 2008) calculated by system optimization (OMC). For Brazil, one can consider the OMC projected or observed, weekly by load level or preliminarily by hour, or even the respective PLD (OMC limited by a price cap). The wind generation can be considered in aggregated or individualized form per wind farm by weekly load level or by hourly basis. The calculation is performed considering the price and quantity of the source generation, and the average price of electricity for the period:



## Results

The analysis of value factor for wind generation in Brazil, calculated through different parameters (PLD, weekly CMO, hourly CMO), observed or projected, can subsidize several analyzes such as (i) comparison with other systems and different markets; (ii) evolution of integration costs in face of greater penetration of wind and Brazilian system transformation; (iii) impact of the price cap level (PLD) on the OMC; (iv) preliminary impact of the introduction of hourly OMC in the Brazilian system, and (iv) comparison of implicitly projected integration costs in the ICB at the auctions and integration costs explicitly observed in the optimized system operation (OMC).

## Conclusions

The installed capacity of wind already exceeds 13 GW of the Brazilian power matrix (8% in 2018), mainly in the northeast, reaching more than 70% of the daily load of the region and 15% of the national system. The value factor analysis of wind generation in Brazil may (i) reinforce the notion of the systemic benefit of wind geeration in the Brazilian system; (ii) better dimension the wind systemic benefit; (iii) point to non-evident or unaccounted integration costs, mainly related to capacity location; (iii) to contrast the systemic value estimated by the value factor with the systemic value implicitly considered in the ICB in power auctions; and (iv) to suggest that the current electricity pricing mechanism in Brazil does not translate the systemic value of sources in the power system under transformation, point out the need for pricing electricity adequately, with sufficient spatial and temporal granularity to remunerate new services, especially related to flexibility provision.

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