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Economic Evaluation of Wind Power Projects in a Mix of Free and Regulated Market Environments in Brazil

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Abstract: The electricity market in Brazil is basically organized under two parts: the regulated market, where energy is traded through auctions, and the free market, where market participants freely negotiate the price and quantity of electricity. Although revenues obtained in the regulated market tend to be lower than in the free market, the auctions' results show that investors still value the lesser degree of uncertainty associated with the regulated market. However, a growing interest in the free market by investors is recognized since the price of electricity tends to be higher. Therefore, this study investigates four free market price scenarios to assess the expected return for investors, using the traditional discounted cash flow approach complemented with Monte Carlo simulation to address market uncertainty. The study breaks new ground by capturing the weekly price fluctuations and including the price elasticity of demand of the free market. The results seem to indicate that the disclosure of the ceiling and floor price limits for the spot price can signal important information about the agents' price expectation in the free market and can be used for investment project evaluation.

Keywords: renewable energy; wind energy; project evaluation; brazilian electrical system

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1. Introduction

Currently, 72% of the world's energy supply comes from non-renewable sources [1]. The environmental consequences of this exploitation have led to a steady growth in the use of renewable energy sources (RES) over the last years [2,3]. In addition, the pressure to reduce carbon dioxide emissions in the electricity generation process, caused mainly by burning coal, may hasten the replacement of non-renewable energy sources by RES in the coming years [3,4].

In Brazil, almost 50% of the power generated in 2019 came from large-scale hydro plants, followed by thermoelectric plants (25%) heavily relying on biomass obtained from large sugar cane plantations, and wind power plants (nearly 13%) [5]. Even so, Brazil still has enormous potential to generate energy from other renewable sources, which needs to be explored. To achieve this, significant regulatory and technological innovations are needed. Although wind power is not the main RES technology in Brazil, in 2020, its installed capacity reached 16 GW [6]. Thus, wind power is one of the most promising technologies in the country, especially in the northeastern region, mainly due to the favorable wind conditions [7]. Brazilian winds are characterized by positive factors related to stability, little variation in direction, and good intensity, which results in a high-capacity factor. In Brazil, the average capacity factor is nearly double that of the world average [6]. The wind power generation sector in Brazil has grown exponentially and become an important alternative source of energy that can help reduce the environmental impact with low production costs. Another important advantage of wind power relates to the existence of more favorable winds during periods of drought, which warrants using wind farms in complement with the hydroelectric plants [8]. In addition to the reduced taxes by the government and the possibility of additional revenues in the negotiation of the carbon market, the high supply capacity of wind power due to the emergence of new technologies with more efficient turbines has made wind generation increasingly competitive in Brazil [9,10].

Wholesale electricity trading in Brazil is based on two markets schemes: Regulated Market (ACR) and Free Market (ACL), both of which are expressed in the Portuguese abbreviation. In the ACR market, the purchase and sale of energy is formalized through auctions by contracts between the generating agents and distributors. In the ACL market, market participants are free to negotiate bilateral contracts to agree upon the volumes of energy and prices between themselves [11]. Until 2018, renewable energy supply contracts in the ACR market were subject to the availability concept, meaning that the company that has won the auction would receive a fixed remuneration for supplying energy, regardless of the amount generated. As of the second half of 2018, companies started to be remunerated according to the amount of energy they were able to supply. However, companies accepted in the auction are required to allocate at least 30% of the electricity production capacity of the project to the ACR market. The 2018 regulatory change tends to increase the risk in these projects as no fixed remuneration for availability is foreseen. Moreover, if the plants are unable to supply the amount of energy agreed upon at the auction, they need to cover the difference by buying energy at a spot price that is higher than the values in the ACR market [11]. This regulatory change poses an important challenge to RES electricity generating companies for assessing the profitability of new investments.

Although the ACR market tends to offer lower prices than the ACL market, the auction results show that companies remain interested in participating in the auction and allocating the required minimum generation share to the ACR market. This is because of the other benefits offered to participants, which go beyond selling electricity. For example, companies participating in auctions enjoy the benefit of using transmission lines granted by government plans [12]. The lower remuneration offered by the ACR market is expected to be compensated by electricity sold under contracts in the ACL market, which usually results in higher revenue. It is, therefore, worth exploring how companies can operate in both markets and what the expected return of such a strategy will be.

Accordingly, this study proposes a new methodological procedure for the decision-making process regarding investment analysis of wind power projects in this new regulatory framework, characterized by a mix of free and regulated market environments in Brazil. The main contributions of the study maybe summarized as follows: it allows a better understanding of the premises that lead producers to invest in the wind power industry under that mixed regulatory environment; the use of the Difference Settlement Price (PLD) as a proxy for the ACL market prices allows to assess whether the price limits released by the Brazilian regulatory agency for the electricity sector (ANEEL) can be used as a reference to estimate the economic viability of the projects; it considers the dynamics between energy supply and demand in the ACL market; and, finally, it presents evidence on the best use of price scenarios to estimate the viability of projects in the ACL market, given the scarcity of information on non-public bilateral contracts between agents in the free market. The research has resulted in the proposal of an investment appraisal methodology, designed and tested for the wind power sector in Brazil, but suitable for adaptation to other sectors and countries that may experience similar regulatory conditions. Further, Aquila et al. [13] and Aquila et al. [14] have proposed a framework for investment analysis of wind power generation projects for the case of Brazil where they take into account different market environments and try to assess the impact of uncertainties associated with those investments. However, due to the above-mentioned regulatory changes that occurred in 2018, a new framework of analysis is needed to fully encompass all those changes and improve the decision-making process. This new framework allows to assess the profitability of wind power generation projects based on the percentage of energy allocated to each market (ACR or ACL) as well as to be easily adjusted when changes in the level of risk and volatility in the ACL market price occur.

The application of the methodological procedure was illustrated using information from the last three wind energy auctions in Brazil that occurred in 2019 and the second half of 2018. At the beginning, the traditional discounted cash flow (DCF) method was used for a deterministic analysis. Then, for a more comprehensive evaluation, a stochastic analysis using the Monte Carlo Simulation (MCS) in a weekly price period that follows a Brownian Motion was performed. Finally, the annual average of these simulations was used for the construction of the annual cash flows of the projects. Although the use of DCF method and MCS simulation for renewable projects evaluation is well established in the literature, to the best of the authors' knowledge, its use on the complex mixed regulated-free market environment to support investors decision making is still an open field for discussion. That is the case of Brazil, which is briefly presented in the following section to provide some contextual background for unfamiliar readers.

2. The Brazilian Electricity System

2.1. Electricity Market Organization

The Brazilian electric system gained importance in the 1960s with large hydraulic constructions and large transmission and interconnection systems for hydroelectric power, which enabled increased efficiency and cost reduction [15]. However, the characteristics of state monopoly regarding the country's electricity sector began to change in the second half of the 1990s. In August 1996, the government implemented the RESEB Project (Restructuring of the Brazilian Electric Sector), as it sought to ensure the economic efficiency of the sector and inviting investments to expand the energy supply. This project was the basis for the new model of the electric sector that would appear in 2004 [16]. The energy crisis that hit the country in 2001 prompted the Brazilian government to implement a new regulatory framework for the sector [17]. With the enactment of the "Law of the new electric sector model" (Law nº 10848/04), the electricity market was segregated into the following segments: generation; transmission; distribution; and commercialization. This disentangled the activities of the companies operating in the electricity sector [18]. The new regulation of the sector also created the electricity trading system with two main markets: the ACR and the ACL. In addition, the Electric Energy Trading Chamber (CCEE) was also created, with the primary aim of making the sale of electricity more efficient.

As previously mentioned, in the ACR market, auctions for the purchase and sale of electricity were characterized by contracts that remunerated producers with a fixed revenue regardless of the quantity of energy offered. As of 2018, these contracts started to remunerate the companies considering the amount of energy offered by them. The new remuneration format started to follow a rule described by Equation (1).

$$RV_{i,m} = \left[\left(\frac{Pot_{delay_{i,m}}}{Pot_{Total_i}} \right) \times P_{(delay_{i,m})} + \left(1 - \frac{Pot_{delay_{i,m}}}{Pot_{Total_i}} \right) \times SP_{i,m} \right] \times CE_{i,m} \quad (1)$$

where,

$RV_{i,m}$ = Revenue of the plant i, calculated in the month m for the ACR market;

$CE_{i,m}$ = Contracted energy of the plant i in MWh, in the month m;

$Pot_{delay_{i,m}}$ = Installed power referring to generating units committed to the contract, which are not in commercial operation after the respective expected dates of granting the power plant i, ascertained in the month m;

Pot_{Total_i} = Installed power referring to the complete motorization of the plant i, in the plot committed to the contract;

$SP_{i,m}$ = Sale price for the plant i, in the month m, defined in auction;

$P_{delay_{i,m}}$ = Resale price, defined according to normative resolution No. 595/13 or another rule that will replace it, in the month m.

Table 1 describes the electricity contracting models in Brazil and compares the main characteristics of ACR and ACL markets.

Table 1. Electricity contracting models in Brazil.

Characteristics	ACL Market	ACR Market
Participants	Generators, traders, free and special consumers	Generators, distributors, and traders
Contracts	Free negotiation between buyers and sellers	Energy auctions promoted by CCEE, delegated by the regulatory agency (ANEEL)
Kind of Contract	Freely established agreement between the agents	Regulated by ANEEL. Called Electric Energy Trading Contract in the Regulated Environment. (CCEAR)
Price	Freely agreed between the agents	Given in the auction

Whenever the producer is unable to supply the contracted amount to the ACR market, it will need to resort to the short-term market (STM) or differences market, to comply with the purchase and sale agreement. The prices of this STM are established by the CCEE and are coined as Difference Settlement Price (PLD). The price of energy in the STM tends to be higher than the prices established by agents at the auction, which leads to higher costs for the non-compliant producer [11]. It is notable that although CCEE calculates the PLD, the maximum and minimum limits for the price are defined by regulations. Between 2015 and 2019, the ANEEL normative resolution No. 633/14 defined these limits.

The main criterion adopted to classify the winners in an auction in Brazil is based on the principle of the lowest bid price per MWh of electricity to ensure reasonable tariff rates. In the recent past, the values of wind energy prices offered in auctions showed a relative downward trend. Concomitantly, the growth of ACL market in the country has attracted the attention of many power producing companies. Figure 1 shows the evolution of the bid prices in wind energy auctions from 2017 to 2019. In the figure, the auctions A-6 (A minus 6) represent a deadline for delivery of the contracted energy within six years of the auction. Similarly, A-3 and A-4 have a contractual delivery deadline of three and four years, respectively. Auctions 2018 (A-6), 2019 (A-4), and 2019 (A-6) are called auctions 28, 29, and 30, respectively, and are used as the primary source of data in this study. The average price established in the auctions, which included 95 projects, was 23.46 USD/MWh. The average value was 23.31 USD/MWh for Auction 28 (2018—A-6), 19.32 USD/MWh for Auction 29 (2019—A-4), and 23.85 USD/MWh for Auction 30 (2019—A-6).

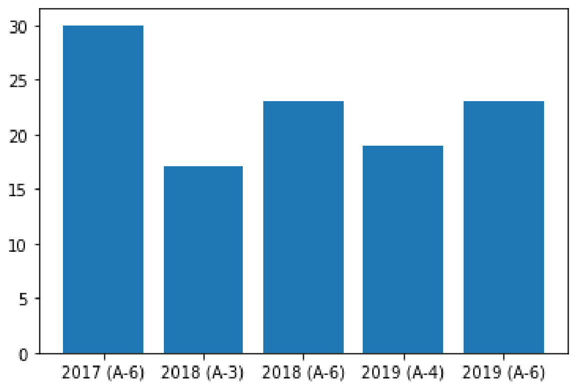

Figure 1. Bid price in Brazilian auctions (USD/MWh). Source: Own elaboration based on data in [11].

The Brazilian electricity system is highly influenced by hydropower plants. As such, the PLD is calculated using mathematical models that seek an optimum balance between hydroelectric plants and the thermal energy usage when rainfall is scarce. Thus, factors related to the demand for electricity, prices of fuels used in the generation of thermal energy, and the emergence of new projects and transmission lines influence the determination of an optimal price for the system, as specified by submarkets. The location distribution of submarkets of the electrical system in Brazil is across four regions: North (N), Northeast (NE), Southeast and Midwest (SE/CO) and South (S). The PLD prices are updated weekly for each regional submarket. Figure 2 shows the evolution of PLD price using monthly averages.

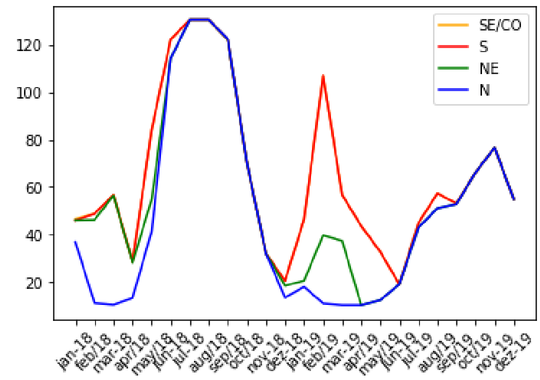

Figure 2. PLD Price in Brazilian Market (USD/MWh). Source: Own elaboration based on data in [19].

The prices stipulated for the SE/CO and S submarkets are overlapping in Figure 2. The internal restrictions of each region are not considered for the PLD calculation. However, energy transmission restrictions between regions are accounted for in the PLD calculation model, which results in different prices for each region. For example, in January and February 2019 the prices in the S and the SE/CO regions peaked, which was due to the forecast of deteriorating water inflows for the system in the region. In contrast, the combination of lower consumption and higher rainfall in the N region maintained PLD at lower values. In 2018, the price values in the N region also followed the rising trend of the other regions due to the shortage of rainfall for all markets and delay in commencing the Belo Monte hydroelectric plant's operations, which is the fourth largest hydroelectric plant in the world. This market splitting requires a regional adjustment of the expected revenue of the projects as PLD is used as a proxy for the price in the ACL market. Given that the projects that won auctions 28, 29, and 30 were all located in the NE region, the PLD for the NE are considered in the analysis.

2.2. Wind Power in Brazil

The environmental impacts generated by the energy sector in Brazil have been a concern since the 1970s, which has boosted the development of research and new technologies aimed at generating renewable energy [9,20]. In 2019, the supply of electricity in Brazil reached a total of 651.3 TWh and registered an increase of 2.3% as compared to 2018. The share of renewable energies in Brazil's electric matrix reached 83% in 2019, and wind energy ranked third place in the order of importance, representing 8.6% of the total electric production matrix [21] (Figure 3).

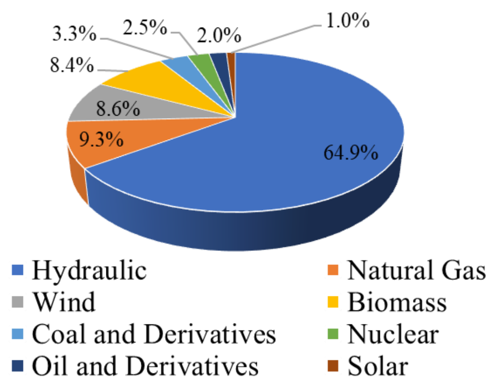

Figure 3. Brazilian electricity production matrix 2019. Source: Own elaboration based on data in [21].

The wind energy industry in Brazil has grown considerably since 2009, becoming a highly attractive Latin American market for this type of investment [22]. In 2019, Brazil generated 56 TWh of electricity from wind energy, a 15.5% growth as compared to 2018 [21]. By 2029, the expansion of installed wind power capacity in Brazil is expected to be approximately 163% of the total recorded in 2019 [23]. Figure 4 shows that installed capacity of wind power in Brazil has grown steadily since 2010, surpassing 15 GW in 2019, representing an expansion of 6.9% as compared to 2018.

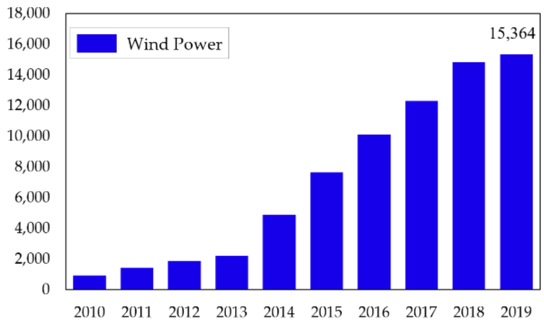

Figure 4. Brazilian wind power installed capacity (MW). Source: Own elaboration based on data in [24].

The large majority of Brazil's wind power capacity is installed in the Northeast region due to the high energy generation potential of the region. In 2019, Brazil had more than 7000 generators distributed in 601 wind farms and 80% of them were located in the Northeast [25]. In addition, the Brazilian Ministry of Mines and Energy (MME) estimated that by 2029, the total installed capacity of wind power in Brazil will reach 39,475 MW [23]. The development of wind energy in Brazil is considered one of the most promising options by the Ministry of Mines and Energy, which has reinforced the industry's competitive advantage to fulfil the demand for electricity in the coming years. The trend of expansion of wind power generation in Brazil shows that, in 2029, this source of energy will correspond to about 17% of the installed capacity of the national electric matrix [23].

3. Materials and Methods

3.1. Methdological Procedure

Figure 5 summarizes the methodological procedure followed in this study.

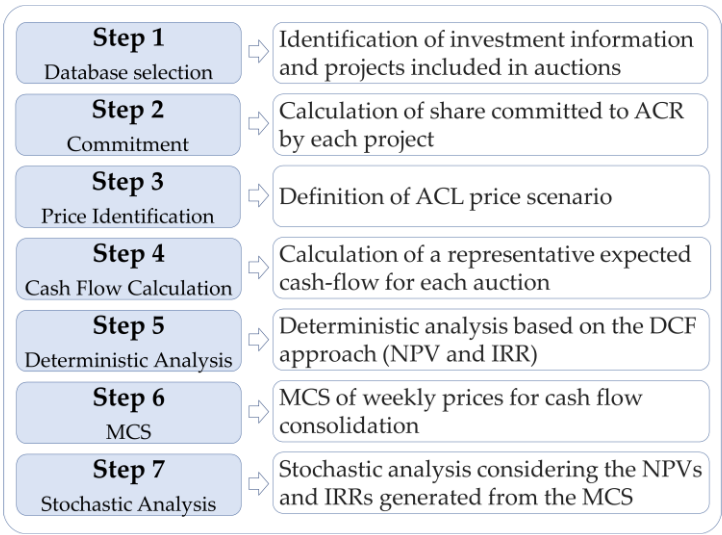

Figure 5. Methodological procedures.

In the first step, the number of participating companies in the Brazilian energy auctions during the second half of 2018 and the entire year of 2019 was investigated. The first auction of 2018 was not considered as it was based on availability and tariff fixed remuneration and not on effective energy supplied. Table 2 presents the number of companies in each auction and that was used to perform the analysis of the financial viability of wind energy projects in Brazil.

In the second step, the percentage of energy committed to the ACR market by each project in the auctions was calculated, according to Equation (6).

$$p_r = \frac{\left(\frac{TES}{tsh}\right)}{Wr} \quad (2)$$

where:

p_r = Percentage committed to the ACR market;

TES = Total energy supply in the regulated market (kWh);

Tsh = Total supply hours, considering 20 years (175,320 h); and

Wr = Physical warranty (maximum available power of the plant (MWh/h).

The variable Wr corresponds to the maximum amount of energy that can be traded through contracts, measured in MWh/h. Wr was established by MME Ordinance No. 258, of 28 July 2008, and was replaced by MME Ordinance No. 101 of 22 March 2016 [26]. Table 2 shows that the companies' commitment to the supply of energy in regulated contracts underwent a considerable reduction in 2019 as compared to 2018. Moreover, the frequency distribution presents a rather dispersed pattern for the first auction in 2018, with almost half of the companies committing less than 50% to the ACR market and the remaining ones committing more than 50% to this market. In this auction, 10 out of the 48 companies committed more than 90% to the ACR market. As for 2019, close to 70% of the companies committed 42% or less to the ACR market and only 3 out of the 43 participants committed more than 90% of their production to the ACR market. Thus, the companies seem to be using a strategy of offering a low share of energy produced to the ACR market and relying mainly on the ACL market for their operations.

Table 2. Number of companies and share of electricity production committed to the ACR market.

Year	Number of Companies	Auction	%	Standard Deviation (%)
2018	48	28	54.69	27.03
2019	3	29	30.24	0.17
2019	44	30	36.27	17.13
Total	95	Average	40.04%	

In the third step, four price scenarios for the ACL market were defined. These scenarios differ in the price used as a proxy for this market. In the first scenario (Scenario A), the price used was the minimum limit of the PLD allowed by ANEEL. Meanwhile, for the second scenario (Scenario B), the price used was the maximum limit allowed for the PLD. In the third scenario (Scenario C), the price used was an average between these limits. Finally, in Scenario D, the price used was an average of the real PLD market prices. In this sense, the average price of Scenario C was called ex-ante, while the average value used in Scenario D was called ex-post. The PLD price was used as a reference to analyze the feasibility of projects in the ACL market since accessing information about the real value of these prices is not public as they are freely determined between the parties that negotiate energy. PLD prices were used as a proxy, mainly, for logical reasons. It would not make sense for a power plant to migrate to the ACL market if the revenue obtained were not higher than that in the ACR market. This suggests that the price of energy in the ACL market should be higher than the minimum PLD price stipulated making selling electricity in the ACL market more profitable than selling in the STM market. In contrast, the price values in the ACL market cannot significantly exceed the PLD price limits because, if that were the case, the buyers would remain in the regulated market, even if it meant buying energy in the STM market. Then, the prices exercised in the ACL market may be related to the expectation of prices in the electricity STM market. Table 3 shows the prices used as a proxy for each scenario.

Table 3. Prices Short Term Market (USD/MWh).

Price\Year	**2018**	**2019**
Min. (A)	10.37	10.23
Max. (B)	130.53	124.12
Average (C)	70.45	67.17
Average (D)	70.78	40.39

Source: [19,27,28].

The electricity price was assumed to follow a Geometric Brownian Motion (GBM), as shown in Equation (3), with the initial price ($t = 0$) given by the price from each scenario. Although there are different methods to simulate electricity prices, the GBM process is widespread in the literature [27], due to the easiness of modeling. For commodity prices, [28] point out that the use of GBM is unlikely to lead to substantial errors.

$$P_{t+1} = P_t + \sigma P_t W_t \quad (3)$$

where, P_t is the electricity price at time t, σ is the standard deviation and W_t is the standard Wiener process.

In the fourth step, based on individual data from each of the 95 projects, what has been called a representative cash-flow per auction was calculated. Two sources of revenues in the cash flow calculation were considered, namely, the energy sold on the ACL market, assuming the free prices scenarios, and the energy sold on the ACR market, accounting for the results of the auction including the committed share of each project and auction price. Due to the length of details and for easiness of understanding, the economic model used to calculate this representative cash flow is described in the following Section 3.2.

In the fifth step, a deterministic analysis for each of the previously calculated representative projects' cash flow was carried out, using the DFC method and assuming fixed scenario prices, to assess the economic viability of the wind power investments.

In the sixth step, the weekly prices obtained in a 10,000-iteration simulation were used to obtain an average of annual prices for each 52-week period. After that, the existence of a gradual elasticity every five years was also incorporated in the calculations, so that the price evolution could reflect in the amount of energy sold. This way, [29] studying the price elasticity of demand among individuals in Brazil found that the elasticity varies between −0.45 and −0.56. This reference was used to trace an evolution of the correlation between price and quantity in the ACL market in four periods of 5 years (−0.15; −0.30; −0.45; and −0.6). With this, it is expected that this readjustment may represent, even partially, the dynamics of the migration of the energy supply to the ACL market and its impact on the reduction of prices.

In the final step, the Net Present Value (NPV) and Internal Rate of Return (IRR) obtained through the MCS simulation were used to perform a stochastic analysis. In this analysis, it was assumed that the main sources of risk associated with the ACL market are the market prices and quantity of energy supplied to the ACL market.

3.2. Data and Cash-Flow Model

This section presents the economic model used to calculate the representative annual cash flow based on the 95 wind energy projects that won the last three auctions of the ACR market (Auctions 28, 29, and 30) that occurred in 2018 and 2019. In the following paragraphs, the parameters used, and the assumptions made related to the cost of investment, revenues, operation and maintenance costs (O&M), transmission fees, leasing, sectoral fees, taxes, depreciation costs, the project's lifespan, and the discount rate, are explained in detail. Table 4 describes some of the main characteristics of the projects presented in these auctions, including the installed power and investment values.

Table 4. Main characteristics of the projects in the auctions.

Auction	Projects' Investments Costs (USD)				Installed Power (MW)			
	Min	Max	Average	Std. Dev.	Min	Max	Average	Std. Dev.
28	9,767,441	89,534,883	31,410,153	16,851,000	8.4	69.3	26.05	15.09
29	20,803,442	53,875,657	42,851,585	15,590,391	21	37.1	31.73	7.59
30	8,115,942	73,043,478	24,642,585	14,161,714	8.4	75.6	23.64	13.83

The data in Table 4 reinforces that the auctions attract projects of different investment values. However, when the investments are weighted by the MW, the values are less dispersed. This is because the dispersion of investment values per MW is not severely affected by the different dimensions of the projects. Almost all investments per MW vary between USD 845,410.63 and USD 1,470,419.15 per MW. Only for Auction 28, four projects presented higher investment values that ranged between USD 1,909,963.42 and USD 2,239,350.31 per MW. This could occur due to external factors such as equipment shortage when constructing the plant at the time of the investment, which directly influences its acquisition price.

The plant's construction period was assumed to be equal to three years from the auction, that is, including the year in which the auction took place plus two more years. The investment amount for the construction was assumed to be released in two tranches of 50% each, with the first tranche disbursed in the year in which the auction takes place and the second tranche in the subsequent year. Although [14] considered a period of two years to be apt for the construction of a wind plant, in this study, three years was considered to account for potential delays.

The sectoral fees followed the assumptions adopted by [30]. The reference of 1% of revenue is the parameter for estimating the fees according to CCEE and the National Electric System Operator (ONS in Portuguese).

The tax costs for the projects account for 1.65% of revenue with regards to the PIS/PASEP rate (taxes paid by companies to finance their employees' social integration programs), and 7.60% of revenue with regards to the Cofins rate (a federal tax created to finance Social Security). In addition, the values of 9% and 15% on the taxable profit regarding Social Contribution and Income Tax, respectively, were also considered. O&M costs were assumed to be equal to 12.5% of project revenues.

Leasing costs were also considered in the calculation of the representative cash flow, and according to [31], the lease of land for wind farms depends on negotiations with the owners of the leased areas, which may vary between 1% and 2% of gross revenue. Therefore, following [14], this work adopted the premise of 1% of the value of the revenue as a reference for this expense.

The depreciation rate of the equipment considered in the study was 5% of the cash-flow per year, allowing for the total depreciation of the investment over the useful life of the projects, which was assumed to be 20 years. This parameter is also found in other studies containing analyses on the depreciation of wind farms [32].

All costs and revenues values were proportionally assigned to the ACR and ACL shares. The only exception was for costs related to transmission fees assigned only to the ACR market. This cost was set at USD 1.60/KW in accordance with Technical Note n. 146/2018-SGT/ANEEL [33], which establishes the tariffs for the use of the transmission system (TUST) for the 2018/2019 period. As specified in ANEEL, it is important to mention that wind farms with power up to 30 MW are entitled to a reduction of at least 50% of these tariffs [34]. For wind plants larger than 30 MW, the full tariff is due.

Finally, the discount rate of 7.66% in 2018 and 7.39% in 2019 was used based on the reference Weighted Average Cost of Capital (WACC) rate for the sector released by ANEEL [35]. The fee charged for the inspection of electricity services (TFSEE) established by ANEEL according to Law No. 9427/1996 was not considered in the calculation because the fee applies exclusively to the consumer; in this case, the generator agent only acts as the fee transfer operator [36].

Table 5 summarizes the data used in this study, including the range of values for the set of projects used in the analysis. Here, the column titled ACRCF presents the values that make up the cash flow of the ACR market portion of the project and the column titled ACLCF presents the same for the ACL market portion. To express price volatility over the years, the percentage of 34.75 was adopted, a value obtained by observing the weekly data provided by [19]. The period consulted was from April 2018 to May 2020.

Table 5. Composition of Cash Flow by market.

Cash Flow Assumptions	ACRCF	ACLCF
Initial Investment	Auction 28: 31,410,153 Auction 29: 42,851,585 Auction 30: 24,642,585	
Duration (Years)	20	
Estimated Production (MWh/year)	Auction 28: 76,668 Auction 29: 44,384 Auction 30: 36,055	Auction 28: 43,556 Auction 29: 102,270 Auction 30: 59,549
Price (USD/MWh)	Auction 28: 23.31 Auction 29: 19.32 Auction 30: 23.85	Table 3
Weekly Volatility (%)	-	34.75
Revenue (USD)	Price × Estimated Production	Price × Estimated Production
(−) PIS/PASEP (% of Revenue)	1.65	1.65
(−) COFINS (% of Revenue)	7.6	7.6
(−) Operational Costs (% of Revenue)	12.5	12.5
(−) ONS/CCEE tariff (% of Revenue)	1	1
(−) Leasing (% of Revenue)	1	1
(−) Transmission cost (USD/kWh)	Auction 28: 30.12 Auction 29: 43.71 Auction 30: 28.49	-
(=) Cash Flow	(USD)	(USD)
(−) Depreciation (% of Revenue)	5	5
(=) Taxable Cash Flow	(USD)	(USD)
(−) Social Contribution	(% Taxable Cash Flow)	(% Taxable Cash Flow)
(−) Income Tax	(% Taxable Cash Flow)	(% Taxable Cash Flow)
(+) Depreciation	(USD)	(USD)
(=) Free Cash Flow	(USD)	(USD)

The cash flow for ACR and ACL are obtained from the assumptions described in Table 5 and are coined as ACRCF (for the regulated market share) and ACLCF (for the free market share). For the sake of simplicity, it is assumed that the initial investment value is equally shared by both the free and regulated markets. Thus, the construction of the complete NPV of the project is expressed in Equation (4):

$$NPV = \left[\sum_{i=0}^{1} 0.5 \times \frac{(-I_0 \times p_r)}{(1+k)^i} + \sum_{i=3}^{N}\left(\frac{ACRCF_i}{(1+k)^i}\right)\right] + \left[\sum_{i=0}^{1} 0.5 \times \frac{(-I_0 \times (1-p_r))}{(1+k)^i} + \sum_{i=3}^{N}\left(\frac{ACLCF_i}{(1+k)^i}\right)\right] \quad (4)$$

where:

$ACRCF_i$ = ACR Cash-flow portion in the regulated market in the year i;
$ACLCF_i$ = ACL Cash-flow portion in the free market in the year i;
I_0 = Initial investment;
p_r = Percentage committed in the Regulated market;
K = Discount rate; and
N = Project's lifespan.

4. Results

This section presents the results obtained with the deterministic approach, and then by adopting the stochastic approach.

4.1. Deterministic Analysis

Before the deterministic analysis of the scenarios, it is worth recalling that the rule for the term of supply of energy for the companies in Auction 29 was 4 years. The other two auctions had, as a rule, a period of 6 years for the supply of energy from the date the contracts were signed. Moreover, the small number of projects participating in Auction 29 (only three) and their massive option for allocating as much energy as possible to the free market is noteworthy. The NPV and IRR were computed for each auction using the representative cash flow and the values are reported for each scenario, as shown in Table 6.

Table 6. Deterministic analysis results.

Scenarios	Auction	NPV (USD)	IRR (%)	IRR–WACC (%)
A	28th	−18,993,520	−1.53	−9.19
	29th	−31,649,641	−5.11	−12.50
	30th	−16,331,533	−3.04	−10.43
B	28th	7,761,046	10.33	2.67
	29th	29,364,263	14.07	6.68
	30th	19,310,951	14.90	7.51
C	28th	−5,619,755	5.46	−2.20
	29th	−1,129,753	7.09	−0.30
	30th	1,538,147	8.09	0.7
D	28th	−5,543,244	5.49	−2.17
	29th	−15,557,752	2.64	−4.75
	30th	−6,880,476	3.86	−3.53

The results for all auctions under Scenario A presented a negative return, as shown by both the NPV and IRR values. The companies that participated in Auction 29 had the most negative NPV values. This is because, among the three auctions, the fewer companies that participated in Auction 29 allocated a higher share of the energy output to the ACL market. Scenario A assumes the minimum PLD prices as a proxy for the ACL market prices and this assumption severely affects the return obtained for this project. Other factors that affected this result are the changes in the WACC and exchange rate of the national currency from 2018 to 2019. Over this period, the WACC decreased by 3.65% and this contributed to improving the values of the projects that started in 2019. These results suggest that when minimum PLD prices are considered for the ACL market, the projects tend to show a negative economic performance. Thus, minimum PLD prices can be considered as a pessimistic scenario for the investors.

In contrast to Scenario A, the results of Scenario B suggest that the auctions with a higher share of electricity allocated to the ACL market showed the best economic performance, both for NPV and IRR indicators. This is the case for Auctions 29 and 30. The results also indicate that the use of maximum PLD values as a proxy for the analysis of the viability of these projects results in IRRs that are much higher than that suggested by the WACC for these types of projects. Although Auction 29 generated a higher NPV than Auction 30 because of its higher installed power and investment, Auction 30 showed a slightly higher rate of return. Auctions 29 and 30 had a larger portion of its revenues concentrated in the ACL market as compared with Auction 28, which benefited these 2019 auctions given the optimistic scenario of PLD prices.

The price used in Scenario C (average ex-ante) scales down the impact of the extremes of values found in Scenarios A and B because it is computed as the average of these values for each auction. As shown in Table 6, the results of Auction 30 suggest that the assumed project is viable, and the values of Auction 29 are slightly below the reference WACC used to assess the viability of projects. The IRR of Auction 28 is also close to the minimum acceptable. The results close to the suggested WACC reinforce the possibility that the projects may have other sources of revenue that are not being considered in this analysis. Accordingly, the electricity that sells under these conditions could bring nearly satisfactory results for most auctions and additional revenues could increase the economic performance of the projects. These additional revenues can come from the reduction of the construction period of the plant and anticipation of the first cash-flows as sales for the free market could be initiated as soon as the project is concluded. This would be possible for all auctions, but it is particularly relevant for Auctions 28 and 30 as the compulsory supply period starts only 6 years from the date the contracts were signed.

According to the results for Scenario D, all projects presented a negative NPV. In this scenario, Auction 28 demonstrated a slightly better result as compared to Auction 30, even though it had a smaller portion of its revenue from the ACL market. This is because the PLD prices in 2018 were higher than those in 2019. In addition, when compared to the prices in Scenario C, both scenarios' prices for 2018 are similar (the PLD prices are 0.45% higher than the prices used in Scenario C). However, when comparing two scenarios' prices in 2019, this is not the case. The PLD prices in 2019 are 31% lower than those of Scenario C, which resulted in the underperformance of projects in Auctions 29 and 30.

4.2. Stochastic Analysis

In the stochastic analysis, two main sources of uncertainty associated with the ACL market were assumed, namely, the market prices and the quantity of energy supplied to the ACL market. For the former, a lognormal distribution for weekly price values with mean in the price itself and standard deviation of 1% of this value was assumed. For the latter, a normal distribution for quantity with mean in the quantity itself and standard deviation of 10% of this value was assumed. The generation of random values for the analysis was obtained by the MCS method, using Python software version 3.8.3, with 10,000 simulations for each scenario, for the representative annual cash flow of the projects of the three auctions. When the simulations were made using the minimum PLD price (Scenario A), the chance that the IRR will be higher than the WACC was out of the 90% probability margin. The result of the simulations for the PLD maximum price (Scenario B) demonstrated a high return value for all simulations, resulting in a highly unlikely scenario, given the characteristics of the investment. For this reason, the scenarios selected for the stochastic analysis were Scenarios C and D. Tables 7 and 8 present the conditions assumed for the simulation.

Table 7. Price conditions for the simulation (USD/MWh).

Auction (Scenario)	Average	Volatility (%).	Source
28th (C)	70.45	34.75 *	[37]
29th (C)	71.86	34.75 *	[38]
30th (C)	71.86	34.75 *	[38]
28th (D)	70.78	34.75 *	[19]
29th (D)	40.39	34.75 *	[19]
30th (D)	40.39	34.75 *	[19]

* The volatility for ACL was obtained from [39].

Table 8. Quantity conditions for the simulation (MWh/year).

Auction (Scenario)	Average	Std. Dev.	Source
28th (C/D)	43,556	30,374.30	[11]
29th (C/D)	102,270.00	24,610.80	[11]
30th (C/D)	59,549.03	43,003.54	[11]

4.2.1. Ex-Ante Average Prices (Scenario C)

The results of the simulations for the projects representing Auctions 28, 29, and 30 are shown in Figures 6–8, respectively. The IRR has a 90% chance of being between 3.45% and 7.15% for the project representing Auction 28; 3.92% and 9.92% for the project representing Auction 29; and 5.19% and 10.96% for the project representing Auction 30.

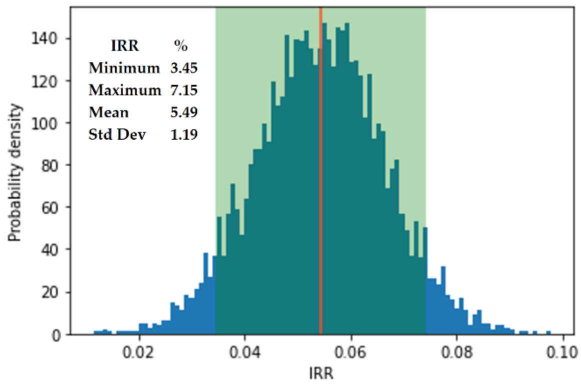

Figure 6. MCS Ex-Ante-IRR 28th Auction. In green, 90% probability range.

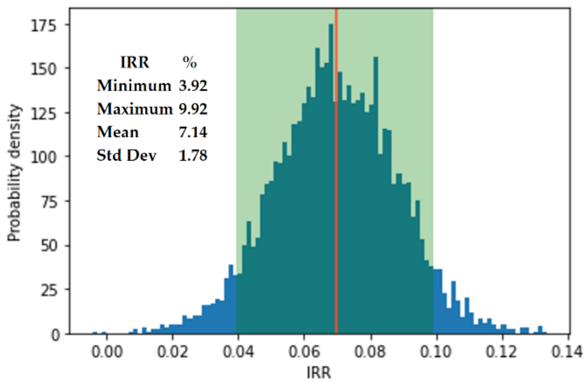

Figure 7. MCS Ex-Ante-IRR 29th Auction. In green, 90% probability range.

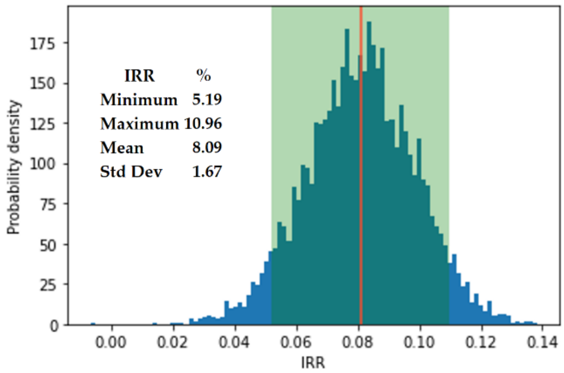

Figure 8. MCS Ex-Ante-IRR 30th Auction. In green, 90% probability range.

When Scenario C's prices were used, the results of the three projects suggested that there are different probabilities for the rate of return to be higher than WACC. In the projects for Auctions 29 and 30, this probability is the highest. For projects of Auction 29, the probability of the rate of return being higher than WACC is 39.8%, while for those of Auction 30 it is 59.7%. For the projects of Auction 28, the probability of the rate of return being higher than the WACC is 4.6%.

From the results of the simulations, it is possible to suggest that projects with greater participation in the ACL market are more likely to have their rates of return higher than the WACC rate. This is because ACL market prices are higher than prices published in auctions. Therefore, it would also be possible to suggest that in order to seek a greater probability of having a rate of return higher than the WACC rate, contracts negotiated in the ACL market may need to establish prices above the average of the minimum and maximum prices authorized by ANEEL. These prices could be lower if the operators were able to obtain sources of revenue other than those estimated.

4.2.2. Ex-Post Average Prices (Scenario D)

Figures 9–11 present the simulation performed for the projects representing Auctions 28, 29, and 30, respectively. The results of the stochastic analysis using ex-post price averages (Scenario D) demonstrate lower economic performance of the projects analyzed as compared to the simulations using ex-ante prices (Scenario C). A peculiarity of this simulation is the low prices registered in 2019, in the results for Auctions 29 and 30. This underscores the fact that the high volatility found in the behavior of PLD prices can compromise their use as price estimators in contracts in the ACL market.

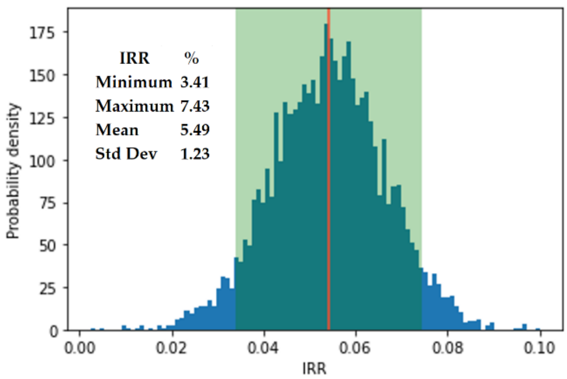

Figure 9. MCS Ex-Post-IRR 28th Auction. In green, 90% probability range.

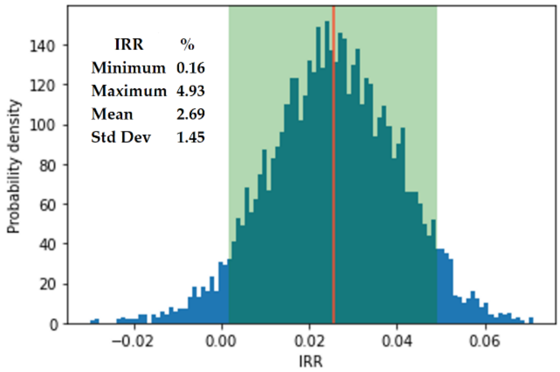

Figure 10. MCS Ex-Post-IRR 29th Auction. In green, 90% probability range.

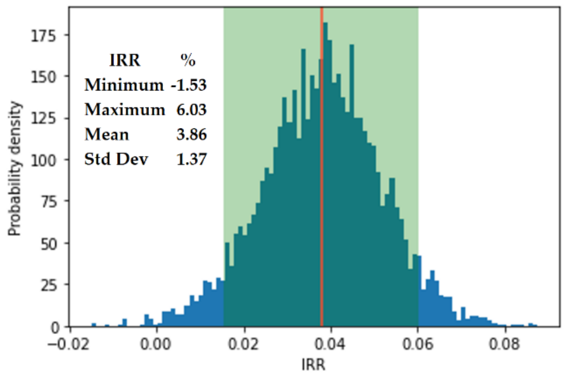

Figure 11. MCS Ex-Post-IRR 30th Auction. In green, 90% probability range.

The results of these simulations, when PLD prices are used as a proxy, show that the probability of projects having a higher rate of return than WACC is considerably low. The prices used in 2019 were lower in the scenario D than in the scenario C. This drop reflects the high volatility found in the spot market. So, this would justify the investors' preference of investing in environments with less volatility, such as the ACL market, which has a greater predictability of revenue through bilateral contracts. This could also help explain the growing preference for the ACL market since 2018. In addition, these results justify the argument that estimating the viability of wind energy projects in Brazil using PLD prices as a reference may not be the most suitable practice for assessing the financial health of the projects. Although the forecast of future energy prices is generally supported by historical prices, in the case of wind energy projects in Brazil, using the PLD historical prices can compromise the analysis of their financial viability.

5. Discussion

The analysis of the economic viability of wind energy projects in Brazil in 2018 and 2019 demonstrated that, under the assumed conditions, the selected projects presented low IRR values, which were frequently below the WACC. This signifies that, under the assumed conditions, the use of PLD prices as a proxy may not the best alternative to estimate the viability of wind power projects that participate in the ACL and ACR markets together.

The absence of disclosure of electricity prices established in bilateral contracts in the ACL market makes it difficult to identify the assumptions adopted by companies in the financial evaluations of their projects. However, the reduction in the percentage of energy committed to the regulated market in 2019 auctions (as close to the minimum as possible) suggests that the companies had a strong expectation of revenue from the ALC market. To identify the values that could help to justify this viability, four reference price scenarios for the ACL Market were outlined: (a) minimum PLD values allowed by ANEEL; (b) maximum PLD values allowed by ANEEL; (c) average values of these limits; and (d) PLD values that actually occurred during the project period.

With the development of the ACL market in Brazil, if the analysis of the feasibility of projects accounts for the fact that revenues are related to both ACR and ACL markets, it can improve the decision making regarding the shares allocated to each market. Thus, this paper proposes a method of analyzing the feasibility for these projects by considering the percentages invested in the two markets: ACL and ACR. This proposal can help banks and financiers to have a more comprehensive view of the economic interest and risks involved in the projects they finance, since it allows a feasibility analysis of the projects weighted by the percentage invested in each market. MCS was then used to account for the uncertainties in the prices of the ACL market and the amount of energy produced by the project. The results indicated that Scenario C produced a higher probability of the return rates being greater than the WACC.

The model's ability to evaluate the market reaction in four periods considering different price elasticity indices contributes to the feasibility estimates of these projects once it considers the potential of the project associated with the changes in the structure of the Brazilian electricity market, which is currently preparing to expand the ACL market model. In a moment when the expansion of the ACL market is a reality for the near future in Brazil, the use of a tool that can contribute to the analysis of the feasibility of projects while identifying this supply and demand dynamics in the market can improve the decision-making process.

As a way of making the analysis closer to reality, the prices in weekly periods were simulated, and only afterwards were the annual averages used. As a result, the short-term characteristics of price behavior have not been disregarded. Furthermore, the identification of reference values for prices that are capable of making projects viable in the ACL are an important indicator for agents working in the regulation of these markets. In this sense, the study showed that using the average of the maximum and minimum prices announced by ANEEL (Scenario C) results in a higher probability of project viability than real PLD prices (Scenario D). Thus, it is possible to suggest that future announcements could influence the dynamics of the choice regarding which market a company would be willing to invest in, that is, the ACR market or the ACL market. The results indicate that, in the absence of information on contract prices in the ACL market, a disclosure of minimum limits and maximum limits for the short-term market by ANEEL may signal some information about the behavior of prices in the ACL market. Although this information is limited, it can provide some guidelines regarding the expected economic viability of the projects.

6. Conclusions

In recent past, the Brazilian wholesale electricity market has undergone an important regulatory change, which poses an important challenge to electricity generating companies for assessing the profitability of their investments. Therefore, this paper provides a new methodological procedure for the decision-making process regarding investment analysis of wind power projects in this new regulatory framework, characterized by a mix of free and regulated market environments. The results obtained seem to indicate that Scenario C produced a higher probability of the return rates being greater than the WACC. This means that the disclosure of the ceiling and floor price limits for the electricity spot price can signal important information about the agents' price expectation in the free market and can be useful information for investment project evaluation and decision.

The minimum percentages allowed for the ACR market by the companies suggests that it is attractive to offer most of the production to the ACL market. The simulations demonstrated that other sources of revenue may justify the economic interest of these wind power projects. Thus, we believe it is important for future studies to analyze these complementary sources of revenue and identify the best time for the company to start building its wind farms from the moment it wins the auction. When the companies win the auctions, a deadline is established to start offering energy in the ACR market. Generally, this interval is longer than the plant construction period. Given this, we suggest that significant additional revenues of the projects may come from the sale of energy by anticipating the construction of the power plants. Therefore, some tools like real option analysis could be used to improve the valuation process, such that the sources of uncertainty existing in the prices exercised in the ACL market are mapped and examined in a more robust feasibility analysis. In particular, given the possibility of participating in the ACL market before the delivery deadline for each auction, the options to anticipate or defer the investment should be considered.

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