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Wind power generation: An impact analysis of incentive strategies for cleaner energy provision in Brazil

Giancarlo Aquila [a], Luiz Célio Souza Rocha [a], Paulo Rotela Junior [b, *], Edson de Oliveira Pamplona [a], Anderson Rodrigo de Queiroz [c], Anderson Paulo de Paiva [a]

[a] Institute of Production Engineering & Management, Federal University of Itajubá, Itajubá, MG, Brazil
[b] Production Engineering Department, Federal University of Paraíba, João Pessoa, PB, Brazil
[c] Department of Civil, Constr. and Environ. Engineering, North Carolina State University, Raleigh, NC, USA

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ABSTRACT

Brazil has adopted various strategies to encourage alternative renewable energy sources in pursuit of cleaner and sustainable energy production. To this end, strategies should support the reduction of the financial risk for potential investors in the renewable energy market. Therefore, this study aims to analyze the impact of incentive strategies on the financial risk of wind power generation projects in Brazil in different marketing environments. From a quantitative approach, using Monte Carlo Simulation in three scenarios, we evaluate the impact of funding from the National Development Bank and participation in the Clean Development Mechanism in the financial returns of the investor in a regulated contracting environment and free contracting environment, measured by the Net Present Value. We conduct a statistical analysis to find out if there were statistically significant differences in investor risk in each scenario. The main results of the study are as follows: the wind speed, the selling price of energy, and disbursement for the investment have the most significant impact on the financial return; the project viability probability is greater than 85% in all scenarios, regardless of the marketing environment; the regulated market is less risky for the producer than the free market, since there is a statistically significant difference in Net Present Value variances for all scenarios; in the regulated contracting environment, funding is critical to reducing risk; and carbon credit trading is not a suitable policy for providing financial security to renewable energy producers. Thus, we conclude that in Brazil the contracting of projects from auctions in the regulated contracting environment, with the support of the National Development Bank, has been important for neutralizing the producer's financial risks.

1. Introduction

Renewable energy sources (RES) can reduce a society's dependence on fossil fuels, which in turn would also reduce greenhouse gas emissions (Shezan et al., 2016; Wesseh and Lin, 2016). Moreover, RES provides energy independence for industrialized countries by reducing exposure to risk associated with the high price volatility of fossil fuels and the risks and geopolitical uncertainties related to the dependence on imports of these resources (Faggiani et al., 2013).

Furthermore, according to Wong et al. (2010), in recent decades, governments of many countries have paid more attention to the issue of climate change. Consequently, several countries have committed to the reduction of greenhouse gas emissions, increasing the need to supply the industries with cleaner energy production from more sustainable sources (Ayodele et al., 2016; Wesseh and Lin, 2016; Ayoub and Yuji, 2012).

Abbreviations: RES, renewable energy sources; FIT, Feed-in Tariff; BNDES, National Development Bank; CDM, Clean Development Mechanism; ACR, regulated contracting environment; ACL, free contracting environment; CCEE, Electric Power Trading Chamber; ANEEL, Electric Power Regulatory Agency; PROINFA, Alternative Energy Sources Incentive Program; PLD, Differences Settlement Price; ONS, National Electric System Operator; SIN, National Transmission Network; MCS, Monte Carlo simulation; O&M, Operations & Maintenance; TUST, Tariff for Use of Transmission System; WACC, Weight Average Capital Cost; CAPM, Capital Asset Pricing Model; IRPJ, Income Tax for Corporations; CSLL, Social Contribution on Net Income.

* Corresponding author. Cidade Universitária, João Pessoa, PB, 58051-900, Brazil.
E-mail addresses: giancarlo.aquila@yahoo.com (G. Aquila), luizrochamg@hotmail.com (L.C.S. Rocha), paulo.rotela@gmail.com (P. Rotela Junior), pamplona@unifei.edu.br (E.O. Pamplona), arqueiroz@ncsu.edu (A.R. Queiroz), andersonppaiva@unifei.edu.br (A.P. Paiva).

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Nomenclature

v	wind speed (m/s)
k	shape parameter
C	scale parameter (m/s)
P	electric power (W)
ρ	air density (kg/m^3)
A_r	area encompassed by the rotor (m^2)
d	rotor diameter (m)
C_P	aerodynamic coefficient of rotor potency
η	efficiency of the generator-mechanical set and electric transmissions
MEP	monthly energy production (kWh)
$v_{\max}$	maximum wind speed (m/s)
$v_{\min}$	minimum wind speed (m/s
NPV	net present value (US$)
r	discount rate
CF_t	liquid cash flow in year t
t	time in years (a)
$P_{NPV>0}$	accumulated probability of positive NPV
$pdf(\tilde{NPV})$	probability density function of NPV
x_i	project's random variables
REC_{CDM}	carbon credit trading revenue (US$)
PG	annual physical guarantee (MW)
P_{co_2}	market price of one ton of carbon (US$)
MAF	average annual carbon emission factor in tonne (t) of CO_2/MWh
k_d	cost of debt
D	weight of debt applied to the investment (%)
τ	income tax
k_e	cost of equity
E	weight of equity in the investment (%)
R_f	risk-free rate
$\beta_{leveraged}$	leveraged beta
R_M	expected market return
R_B	Brazil risk premium
$\beta_{unleveraged}$	unleveraged beta

The demand for energy in Brazil, primarily in the industrial sector, has increased over the past decades (EPE, 2014), which consequently increases the risk of emission of greenhouse gases. In this aspect, Queiroz (2016) and Davis and Martin (2014) emphasize that the RES has an important role in promoting sustainable development, and new investments in RES are needed to meet the growing energy demand.

Simons and Cheung (2016) and Aso and Cheung (2015) explain that wind power is one of the sources that contributes to the reduction of carbon emissions, with low operating and maintenance costs during production. However, according to Ayoub and Yuji (2012), the major obstacle to the electricity generation from RES, such as wind power, is the cost of technology.

To overcome this obstacle and attract financial investors in wind power generation projects, Brazil has adopted the system of contracting renewable energy generation projects through auctions with the support of National Development Bank (BNDES) credit lines. Furthermore, the renewable energy producer can apply to participate in the Clean Development Mechanism (CDM) established under the Kyoto Protocol, in which it is possible for the producer to receive carbon credits to be sold (Watts et al., 2015).

Therefore, this study aims to analyze the impact of incentive strategies on the financial risk of wind power generation projects in Brazil in different marketing environments. To do so, we assess the impact of BNDES financing and participation in the CDM on investors' financial returns in both existing marketing environments in Brazil.

Similar to the following studies in analyzing the financial risk of the investor in places that adopt some mechanism to encourage wind power generation projects (Li et al., 2013; Mudasser et al., 2013; Walters and Walsh, 2011), this proposed study uses a Monte Carlo Simulation (MCS) method for the project investment analysis. However, a quantitative analysis of the impact of different marketing environments and between support mechanisms is rarely found in the literature. It is also important to note that this study presents a statistical analysis to facilitate comparison of the risk between the analyzed scenarios.

2. Power generation in Brazil

Historically, the government has an important role in the Brazilian electricity sector. When the privatization process began, by the early 1990s, the state controlled almost the entire sector. Despite the privatization process, the majority of power generation assets remain under the Brazilian government's control (Silva et al., 2016).

In 2004, a new trading model was created in the Brazilian electricity sector, establishing two energy trading environments: the regulated market, known as the regulated contracting environment (ACR) and the free market, known as the free contracting environment (ACL). Approximately 72% of all electricity is traded in the ACR and approximately 28% is sold in the ACL (Devienne Filho, 2011).

Currently, in the ACL, energy producers, including major producers of wind power, are free to negotiate the purchase of energy, setting volumes, prices, and supply deadlines. The electricity in the ACR is sold at public auctions in order to meet the existing demand (Dalbem et al., 2014; Mastropietro et al., 2014), and the hired company is the one that offers electricity in auction at the lowest price. The electric power auctions held by the Electric Power Trading Chamber (CCEE), by delegation of the Electric Power Regulatory Agency (ANEEL), occupies a key role in electricity energy contracting in the ACR.

Government intervention in the renewable energy sector is also clearly noted. Although Brazil has one of the largest hydroelectric potential in the world (Silva et al., 2016; Mastropietro et al., 2014), the dependence on water resources has raised questions about the social and environmental impact due to construction of large dams, in addition to the drought that caused widespread blackouts in 2001–2002, and led the discussion on the need to expand the participation of new sources for energy supply in the country's energy matrix (Juárez et al., 2014).

However, according to Wachsmann and Tomalsquim (2003), until 2001, there were no incentives, which made it difficult for entrepreneurs of small renewable energy projects established in Brazil. It was only with the creation of the Alternative Energy Sources Incentive Program (PROINFA) that Brazil actually witnessed the implementation of a wider policy directed toward the renewable energy sector. The PROINFA had as a goal to contract 3300 MW in green power generation projects, divided equally between wind, biomass, and small-scale hydropower (Dutra and Szklo, 2008).

The program was supported by special funding schemes through BNDES with a minimum requirement of national equipment participation in contracted projects. Subsequently, a second phase of PROINFA, also based on Feed-in Tariff (FIT), was planned. However, since 2007, the country gradually began hiring enterprises for renewable energy generation through auctions.

Since PROINFA's creation, wind power has grown in participation in the Brazilian energy matrix. According to Silva et al. (2013), Brazil has more wind turbines than any other Latin American country. In August 2012, Brazil had about 2 GW of wind power installed. In December 2014, according to ABEEÓLICA (2015), this value had already reached 5.9 GW, constituting 4.4% of the national energy matrix.

In addition, in both ACR and ACL, if the producer cannot generate 100% of the energy signed in the contract, the producer will have to buy this energy in the spot market, liquidating and accounting for this difference to meet the ballast established in hiring (CCEE, 2010).

In this respect, the producer is also exposed to the Differences Settlement Price (PLD), used to value the energy sold in the spot market. The PLD is calculated by using data considered by the National Electric System Operator (ONS) to optimize the operation of the National Transmission Network (SIN).

2.1. Energy production calculation for wind power generators

In Brazil, because the uncertainty of wind power generation is of paramount importance to calculate the settlement of differences valued by PLD, the use of statistical techniques becomes even more relevant to incorporate wind behavior uncertainty in the financial analysis. For a statistical analysis of wind characteristics and wind energy potential, the Weibull distribution is enshrined in the literature, being considered as the most suitable method for wind speed approximation (Usta, 2016; Safari and Gasore, 2010; Akdag and Guler, 2009).

Safari and Gasore (2010) state that the use of the Weibull distribution is suitable for simplicity to estimate the parameters that approximate the empirical distribution of wind observations. The probability density function of a Weibull distribution is given by Equation (1), according to the proposal by Justus et al. (1978):

$$f(v) = \frac{k}{C}\left(\frac{v}{C}\right)^{k-1} e^{-\left(\frac{v}{C}\right)^{k}} \tag{1}$$

where v represents the wind speed (m/s); k denotes the shape parameter; and C represents the scale parameter (m/s).

Naturally, in calculating the wind energy potential, wind speed is one of the determinant input variables for obtaining the power produced. Custódio (2013) explains that the energy supplied by a wind turbine varies with the cube of the wind speed and the diameter of its rotor. The electric power in Watts (W) is given by Equation (2):

$$P = \frac{1}{2}\rho A_r v^3 C_P \eta \tag{2}$$

where ρ represents the air density (kg/m^3); A_r represents the area encompassed by the rotor ($\pi d^2/4$, where d is the rotor diameter); v denotes the wind speed (m/s); C_P stands for the aerodynamic coefficient of rotor potency; and η denotes the efficiency of the generator-mechanical set and electric transmissions.

For the current study, the following values were considered, according to manufacturer's specification: $\rho = 1.225$ kg/m^3; $d = 82$ m; and $\eta = 0.98$.

Custódio (2013) emphasizes that with respect to C_P, the value is dimensionless and varies with a site's wind speed. However, using a cubic regression, it is possible to update the value of the C_P based on random wind speed values that are generated from Monte Carlo simulation (MCS). The data employed in this regression are shown in Table 1.

Regarding the C_P, Equation (3) presents the function obtained by cubic regression made through 25 wind speeds values for turbines' C_P performance. According to Hair et al. (2014), the regression equation should have an adjusted R^2 above 70% to be acceptable. Thus, given that the equation obtained showed an adjustment larger than 70%, it may be considered appropriate ($R^2_{\text{adj}} = 94.3\%$):

$$C_P = -0.08114 + 0.1771v - 0.01539v^2 + 0.00034v^3 \tag{3}$$

It is generally possible to accurately estimate the production of a wind power, considering two the Weibull distribution parameters, k and C, plus the air average density (Amarante et al., 2001). Thus, the Monthly Energy Production (MEP) for a wind power turbine can be calculated by integrating potency curves and the frequency of wind speed (see Equation (4)):

$$MEP = 0,73\text{x} \int_{v_{\min}}^{v_{\max}} P(v)f(v)dv \quad (\text{kWh}) \tag{4}$$

This calculation is important to assess the plant's monthly energy production, which should be compared with the amount of energy that the plant can trade, called physical guarantee. The physical guarantee concept is similar to firm-energy rights, presented by Faria et al. (2009), which refers to the maximum continuous power generation of hydroelectric plants over a given period. In the case of wind farms, the physical guarantee is calculated after conducting studies on the wind profile in the region during a given period, which are essential for the proper calculation of this parameter.

2.2. Techniques for investment and risk analysis in wind farms

Investment analysis has been used in several studies to measure the impact of incentive strategies for renewable energy sources in different locations, which proves the importance and potential of this type of analysis. Several studies in the literature, such as

Table 1
C_P × Wind speed.

C_P	Wind speed
0	0
0	1
0.12	2
0.29	3
0.4	4
0.43	5
0.46	6
0.48	7
0.49	8
0.5	9
0.49	10
0.42	11
0.35	12
0.29	13
0.23	14
0.19	15
0.15	16
0.13	17
0.11	18
0.09	19
0.08	20
0.07	21
0.06	22
0.05	23
0.05	24
0.04	25

Mudasser et al. (2013), Grieser et al. (2015) and Testa et al. (2016), perform project feasibility analyses related to renewable energy generation through the decision criteria of the Net Present Value (NPV). The NPV for time 0 is given by Equation (5).

$$NPV = \sum\nolimits_{t=0}^{n} \frac{CF_t}{(1+r)^t} \tag{5}$$

Where r represents the discount rate; t denotes the time in years; and CF_t stands for the liquid cash flow in year t.

Since several risk factors affect the NPV result of a wind power project, these factors were considered as random variables (Li et al., 2013). Thus, the synthesis of all iterations generates a range of possible results (Tziralis et al., 2009). Since an economically attractive project in this study has an NPV >0, at a certain discount rate (r), the probability of feasibility is given by Equation (6):

$$P_{NPV>0}(x_1 \ldots x_n; r) = \int_0^{+\infty} pdf\left(N\tilde{P}V\right) dN\tilde{P}V \tag{6}$$

where $P_{NPV} > 0$ represents the accumulated probability of positive NPVs in the project; $pdf(N\tilde{P}V)$ represents the probability density function of NPVs in the project; and x_i denote the project's random variables.

3. Data and method

The methodology used in this research is characterized by modeling and simulation. Bertrand and Fransoo (2002) explain that the research methodology for modeling and simulation is based on quantitative models and on the assumption that it is possible to construct objective models that explain real processes' behavior.

The MCS is a technique that uses the probability distributions of different stochastic variables to perform multiple iterations in order to provide the impact of uncertainty of the input variables on the final results (Kamali et al., 2016). Moreover, this technique is used in the renewable energy field by authors such as Kamali et al. (2016), Arnold and Yildiz (2015) and Montes et al. (2011). Li and Lin (2016) explain that the MCS refines the accuracy of the analysis results.

For this study, we chose the project located in the state of Bahia, in northeast Brazil, owing to the existing wind potential in the region. Several complexes of wind power generation are located in this region. The technical data of the project are summarized in Table 2, in which the used data follows similar characteristics to the projects implemented in most wind farms found in the region.

The calculation of the investment considers the typical composition of wind generation projects in Brazil (70% for wind turbines, 15% civil construction, 10% electrical network, and 5% project and administration) as indicated by Custódio (2013). However, for the investment value, this study uses the average of investments in winners project of the alternative sources' auction that occurred in April 2015. The average value of investments is US$ 47,701,655.84. It is worth noting that the energy selling price is considered as the average value of the same auction prices, i.e., US$ 57.62 (CCEE, 2015).

Table 2
Technical data of the wind farm project.

Parameter	Value
Maximum power	30 MW
Number of wind turbines	15
Power of each wind turbine	2 MW
Installation height	80 m
ρ	1.225 kg/m^3
d	82 m
η	0.98

Regarding the values corresponding to the operating expenses, the annual value data for lease payment, Operations & Maintenance (O&M) costs (including administrative costs), and insurance expenses, were extracted from the Aeolian-Electric Manual (COPEL, 2007).

For Tariff for Use of Transmission System (TUST), this study considers the amount paid by the plants connected to a transmission line located in southern Bahia. From this value, a 50% discount is given for plants with power up to 30 MW (ANEEL, 2011). To estimate the fees paid to ONS and CCEE, we divided the annual budget of the respective organizations by the total energy produced in the SIN. The ANEEL fee was calculated based on the methodology described in ANEEL (2015b).

Expenditures on settlement differences are calculated from the difference between the physical guarantee and the energy generated by the plant each month, this was calculated by using Equation (4), and multiplied by the monthly PLD (CCEE, 2010). To calculate the annual cost, expenses for the months of each year are added.

The calculation for the revenue from carbon credit trading is represented by Equation (7), as recommended by BNDES (2009). The carbon price per ton corresponds to the average between the period from 05 to 12-2015 to 06-12-2015 and the emission factor is equivalent to the reference value released by MCIT (2015).

$$REC_{CDM} = 8760 \times PG \times P_{co_2} \times MAF \tag{7}$$

Where REC_{CDM} represents the carbon credit trading revenue (US$); PG denotes the annual physical guarantee (MW); P_{co_2} represents the market price of one ton of carbon (US$); and MAF represents the average annual carbon emission factor in tonne of CO_2/MWh.

The BNDES funding conditions until May 2015 for wind farms are as follows: interest rate after deducting the inflation rate of 3.76%, repayable in 16 years after the plant's entry into operation and a grace period of 6 months.

The wind farm discount rate calculation was based on Weighted Average Capital Cost (WACC). The WACC is obtained through the calculation in Equation (8) (Ertürk, 2012).

$$WACC = k_d D(1-\tau) + k_e E \tag{8}$$

Where k_d represents the cost of debt; D stands for the weight of debt applied to the investment (%); τ denotes the income tax; k_e represents the cost of equity; and E denotes the weight of equity in the investment (%).

To obtain the cost of debt, we assume the final interest rate percentage, discounting inflation, to obtain funding from BNDES. For the calculation of the cost of equity, the Capital Asset Pricing Model (CAPM) was employed, adding the country risk premium similar to what is adopted by Ertürk (2012) and recommended by ANEEL (2015a) with a value of 2.62%. Equation (9) presents the CAPM model for the current study:

$$k_e = R_f + \beta_{leveraged}\left(R_M - R_f\right) + R_B \tag{9}$$

where R_f represents the risk-free rate; $\beta_{leveraged}$ denotes the leveraged beta and measures the project risk in regards to the market; R_M represents the expected market return; and R_B stands for the Brazil risk premium.

The leveraged β was calculated from the unleveraged β for the renewable energy sector, which is given in the sector beta table by Damodaran (2015); the value is 0.63. For the calculation, we considered a capital structure of 70% of debt and 30% of equity and τ

equal to 34%. The procedure for obtaining leveraged beta as given in Equation (10) rendered beta leveraged equal to 1.60:

$$\beta_{leveraged} = \beta_{unleveraged}\left(1 + {}^{D}\!/_{E}\right)(1 - \tau) \tag{10}$$

where D represents the weight of debt capital applied to the investment (%); E stands for the weight of equity in the investment (%); and τ denotes the income tax.

The R_f, R_M, and R_B values used in the CAPM calculation were 5.64%, 13.20%, and 7.56%, respectively, as indicated in ANEEL (2015b). Using this data, we calculate the WACC as 6.99% per year. Table 3 shows the main information related to the project's financial assumptions.

To prepare the cash flow, whose structure is characterized in Table 4, the funding and capital cost interest rates are discounted by inflation rate. We considered the value of 5.6% for inflation, corresponding to the expected inflation considered by ANEEL (2015a).

After discount rate calculation, we conducted a deterministic analysis in which we did not consider the uncertainties in the most sensitive variables for NPV results and in the variables related to the generation of uncertainties and exposure to spot market.

To select the variables in which uncertainties have been incorporated, Arnold and Yildiz (2015) recommend performing a sensitivity analysis that saves time for the implementation of MCS, because it restricts the number of input variables, by choosing only the most significant variables for generating the results of the deterministic model. Therefore, we performed a sensitivity analysis in which we identified the most impactful variables in NPV.

Once the sensitivity analysis has been carried out, the uncertainties are included in the variables that influence the results of NPV and also in those referring to the average monthly speed wind, which generates uncertainties in energy production by wind turbines. Besides, the uncertainties are applied to PLD and to annual reference values through which the profits or losses due to exposure of the wind energy producer to the spot market in Brazil are quantified. Then, we performed the MCS generating 1000 NPV results for each scenario with their respective variances.

It is interesting for wind power producers to compare the risks to which they may be exposed to, since, in Brazil, the producer can trade power in different market environments (Dalbem et al., 2014). Therefore, we applied Levene's test, which is used to evaluate the homogeneity of variances between different data sets. In case the variances are equal, we consider that the data from different groups are homogeneous. The advantage of this test is that it does not require the normality assumption (Carrol and Schneider, 1985).

The wind farm has the possibility of selling energy in the ACR, which would be hired at an auction of energy, or ACL. In both environments, contracts are for quantity, in which the producer takes monthly risks to meet the amount of energy generation sold. Therefore, in this study, three scenarios were analyzed for each type of marketing environment: 1. without funding and carbon credits; 2. with funding and without carbon credits; and 3. with funding and carbon credits. In the last scenario, it is considered that the project could be part of the CDM during a period of 10 years, in which carbon credit trading is possible. The three scenarios were selected because they involve relevant incentive strategies for the investor in wind power generation projects in Brazil (Pereira et al., 2012; Martins et al., 2013; Watts et al., 2015). Fig. 1 summarizes the scenarios analyzed in this study.

In all scenarios, the cash flows do not consider inflation and these are based on quantity contracts in which the producer assumes the plant's monthly generation risk. Since, in ACR, the contract period of wind projects is generally 20 years after the plant commences operation, and the average lifetime of the wind turbines also revolves around this same time, we define this as the project planning period in the two trading environments. In this study, we only consider a possible situation in the ACL, where the entrepreneur could only close annual contracts for energy trading during a planning horizon of 20 years.

4. Results and discussion

Initially, the sensitivity analysis was performed. Arnold and Yildiz (2015) also emphasize that in the sensitivity analysis a single input parameter varies systematically within a predefined range of values. In the case of this study, all relevant input parameters of the model varied in a range of −10% to +10% related to the listed values. These changes will impact the output variable model, in this case the NPV. After applying variations for each parameter, we selected only those that caused greater deviations in the outcome

Table 3
Data relating to the analyzed wind farm project.

Parameter	Value
Investment	US$ 47,701,655.84
Project lifetime in years (a)	20
Installed power	30 MW
Energy sales price (US$/kWh)	US$ 57.62/kWh
Plant operating time	8760 h/a
Power supply physics guarantee	13 MW
Lease	1% of gross revenue
O&M costs (including administrative expenses)	12% of gross revenue
Tariff for Use of Transmission System (TUST)	US$ 0.87/MW
CCEE fee	US$ 6.49/kW
ONS fee	US$ 25.97/kW
ANEEL fee	US$ 22,552.99/a
Expenses insurance	0.30% of investment
Tax on gross revenue	7.60% (Cofins) and 1,65% (PIS)
Income Tax for Corporations (IRPJ)	25% on 8% of gross revenue
Social Contribution on Net Income (CSLL)	9% on 12% of gross revenue
Debt payment period in years (a)	16
Discount rate − WACC (%) (without inflation)	6.99%
Emission factor	0.1355 kg (CO2)/kWh
Carbon price	€ 7.46/t
Euro value	US$ 1.12
CDM annual registration fee	US$ 1594.74

Table 4
Wind farm project cash flow.

Gross revenue: energy sales, settlement of differences and carbon credit sale
(−) Tax collected on gross revenue
(=) **Net Income**
(−) Operating expenses
(=) **Operational result**
(−) Additional expenses with settlement of differences
(−) Investments
(−) Financial expenses and debt amortization
(=) **Free cash flow to Equity**

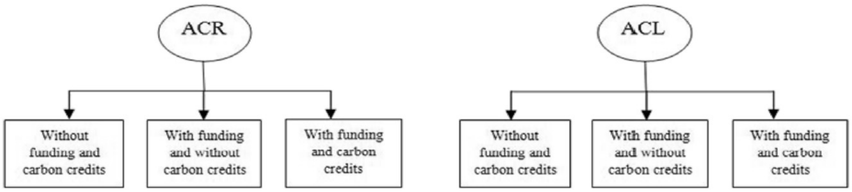

Fig. 1. Analyzed scenarios.

found in the deterministic analysis of NPV. The sensitivity analysis results are illustrated in Fig. 2.

From the sensitivity analysis results, it appears that the most significant variables are wind speed, energy selling price, and disbursement related to investment. Regarding the wind speed, this is a key variable for calculating the physical guarantee of energy that the producer is able to ensure in the contract. Thus, similar to the studies presented by Walters and Walsh (2011), Mudasser et al. (2013), and Ayodele et al. (2016), the wind speed is a crucial variable for the viability of wind power generation projects.

The energy selling price proved to be essential to the variability of NPV, as presented by Ayoub and Yuji (2012), Ertürk (2012) and Grieser et al. (2015). Thus, once the importance of the energy selling price has been shown, it is possible to highlight that auctions remain important properties of an FIT program, eliminating the uncertainty about the amount of energy to be sold and ensuring a long-term fixed remuneration to the producer.

As shown in Blanco (2009), Montes et al. (2011) and Grieser et al. (2015), the other relevant variable for the NPV results is the investment. In the case of this variable, the investor is exposed to economic variables such as the exchange rate and the wind turbines cost. In the case of marketing in ACR, investment remains the only uncertain variable among those identified in the sensitivity

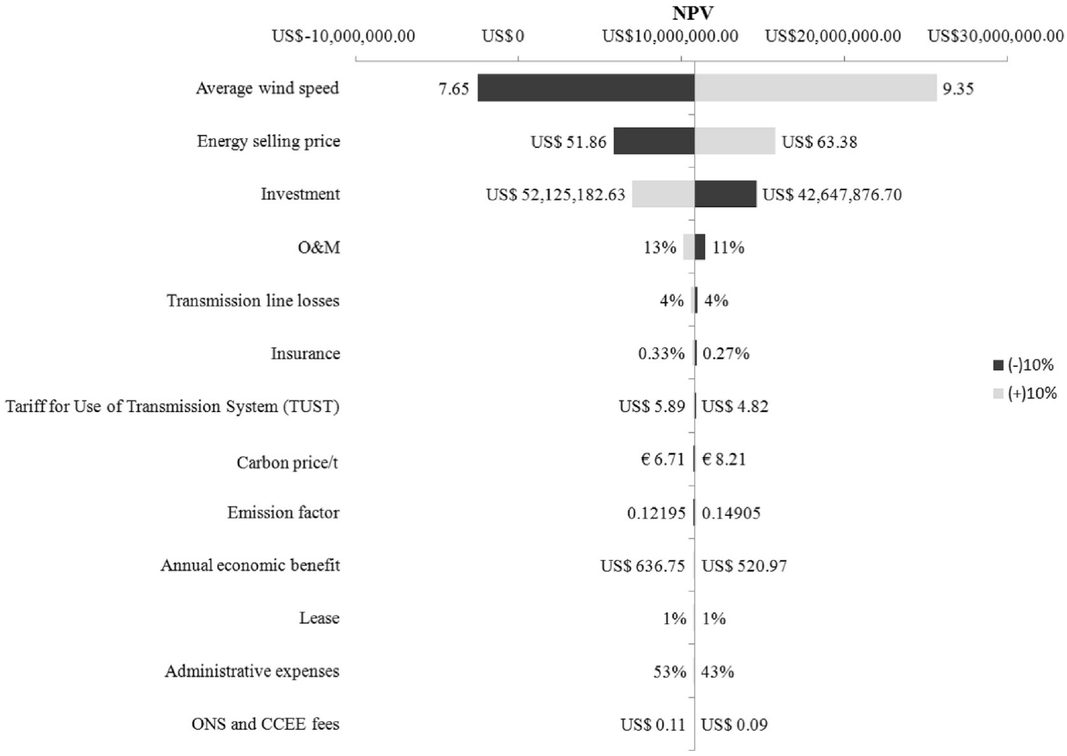

Fig. 2. Sensitivity analysis results.

analysis, since the amount of energy sold and the price of energy are fixed over the 20 years.

It is worth noting that the other variables did not cause more than 3% of NPV variation found in the deterministic analysis. Thus, in the MCS, we consider the uncertainties in the variables related to the investment, the average wind speeds, the PLD, and the annual reference value. Therefore, we use their respective probability distributions.

For the scenarios analyzed in the ACR, uncertainties are not embedded on price and on quantity of energy contracted, since the regulated environment precisely counteracts these variables. In the ACL, we consider the possibility of changes in price and amount of energy contracted, being the selling price uncertainties represented by PLD.

The PLD probability distributions for energy prices are the same considered for the monthly PLD, whereas in Brazil, it is still not possible to obtain an annual PLD series long enough to provide statistical parameters of a probability distribution.

Although there is consensus that energy demand is growing and hardly be lacking demand for energy produced in Brazil, we consider that the producer could trade at least 90% of his physical guarantee for buyers in ACL.

Regarding investment, the values are based on the investment range of winner participants in auctions conducted in Brazil between 2013 and 2015. These auctions had been addressed to wind farms with a capacity of 30 MW, whose values are available on the CCEE website.

In Table 5, it is possible to assess the probability distributions and their parameters for the main variables that include uncertainties, which could modify the NPV results.

In Table 6, we highlight the average wind speed and the scale parameter (*C*) of Weibull distribution used for the wind speed for each month of the year. The value used for the shape parameter (*k*) was 2.41, corresponding to the lowest value with two decimal places in the range of $2.4 < k < 3.7$ indicated by the air-speed measurements monitoring report for Bahia state (EPE, 2013). This shape parameter value was chosen with an aim to achieve a more conservative analysis, because it reduces the possibility of extreme values of average wind speed.

After uncertainties have been incorporated in variables described in Tables 5 and 6, we conduct 1000 simulations for NPV results in the three discussed scenarios. We call Scenario A, the situation where there is no presence of funding and trade of carbon credits; Scenario B, where there is presence of funding, but not trading of carbon credits; and Scenario C, which contains the presence of funding and trade of carbon credits.

The NPV mean and viability probability results for wind farm simulation are presented in Table 7.

As seen in Table 7, the viability probability of the analyzed project in the three scenarios, both in ACL and ACR, are above 85%. This is an important result because it shows that this type of project is very likely to be feasible, similar to the results found by Ertürk (2012) and Montes et al. (2011), in Turkey and Spain, respectively. However, these studies did not include a comparison between different marketing environments. When comparing the impact of funding and the possibility of carbon credits trade, in ACL and ACR, we note that the ACR suffers the greatest impact for these variables. This is because the energy selling price, which is the second variable that most impacts the result of NPV, is fixed in the ACR whereas in ACL the price fluctuates according to the market.

Table 6
Average wind speed probability distribution parameters.

Month	Monthly average wind speed	Weibull parameters (*C*; *k*)
January	8.375	(9.44; 2.41)
February	9.158	(10.33; 2.41)
March	9.063	(10.22; 2.41)
April	7.895	(8.90; 2.41)
May	8.640	(9.74; 2.41)
June	9.266	(10.45; 2.41)
July	9.881	(11.14; 2.41)
August	10.297	(11.60; 2.41)
September	10.079	(11.36; 2.41)
October	9.761	(11.00; 2.41)
November	7.402	(8.35; 2.41)
December	7.038	(7.94; 2.41)

Table 7
Simulation results.

Scenario	ACL		ACR	
	NPV mean	Probability	NPV mean	Probability
A	US$ 35,686,062.50	96.36%	US$ 7,904,013.72	85.02%
B	US$ 41,744,591.75	97.70%	US$ 14,729,251.27	99.04%
C	US$ 43,182,768.39	98.50%	US$ 15,781,463.28	99.58%

When we compare the NPV of the two environments, the ACL generated much higher NPV means than the ACR. However, this result can be misleading, since energy price can range from US$ 5.71 to US$ 228.57. Although in the last eight years, the price of energy had many peaks, these high values favored the ACL in MCS. As expected, the NPV values in both environments have increased with the possibility of funding and sale of carbon credits, in accordance to Silva et al. (2013) and Li et al. (2013), respectively.

With scenarios' variance, it is possible to find out whether there is a statistically significant difference in the producer's risk in each scenario, by applying the Levene's test. Initially, we compare the statistical difference of the variances between each similar scenario analyzed in the ACL and ACR. As the adopted confidence level was 95%, p-values lower than 0.05 reject the hypothesis that the variances are statistically equal. Table 8 shows the variance and the results of Levene's test, performed using the Minitab software.

The Levene's test results reveal that there is a statistically significant difference in the producers' risk between trade in ACL and ACR. The conditions offered in the ACR counteract the uncertainties

Table 8
A comparative analysis of producer's risk in ACL and ACR.

Scenario	ACL variance	ACR variance	P-value
A	US$ 5.50105×10^{14}	US$ 4.8635×10^{13}	0.000
B	US$ 6.11666×10^{14}	US$ 4.1337×10^{13}	0.000
C	US$ 5.63248×10^{14}	US$ 3.9467×10^{13}	0.000

Table 5
Probability distributions.

Variable	Used distribution	Distribution parameters
Investment	Triangular	(32,467,532.47; 47,701,655.80; 61,688,311.69)
PLD	Gamma	(7.13; 154.99; 0.55)
Annual reference value	Triangular	(25.97; 38.96; 48.70)
Amount of energy sold in ACL	Triangular	(11.73; 13.04; 13.04)

in price and amount of contracted energy, which makes the producer returns variance lower than in ACL. Moreover, the ACL can expose the producer to contracts with uncertain revenues, contributing to the significant difference between the producer's risk in the analyzed environments. Although there are different periodicities for contracts in ACL, this study considered the one-year contract over the 20 years of operation of the wind farm.

Note that the variance is high in both marketing environments and reaches the trillions. This is due to exposure in the spot market and energy generation uncertainties, which can lead the producer in the low wind-speed period to pay a high amount in the spot market to settle the energy that should have been produced.

We also compared the variances between each scenario in the same trade environments. The results are presented in Table 9.

The results in Table 9 reveal an important role of BNDES as additional support to the uncertainty containment policy provided by ACR. Only the comparison between AxB and AxC scenarios showed statistically significant differences between variances, indicating that funding reinforces risk reduction of the producer's returns. Furthermore, comparing the BxC scenarios, there were no statistically significant differences between variances. This allows us to conclude that despite the increase in revenues, carbon credit sales do not contribute significantly to the reduction of producer risks. This result is different from that presented by Li et al. (2013) when analyzing the Chinese case.

The results obtained through the techniques used provide an important basis for investors to compare their financial returns according to market circumstances in which they can be inserted. Moreover, the results also provide important guidelines for formulators of public policies to understand which mechanisms have greater potential to attract new producers of RES to the country.

5. Conclusions

This study analyzed the impact of incentive strategies on the financial risk of wind power generation projects in Brazil in different marketing environments. The incentives that affect financial returns in different market environments have been considered in the analysis are (i) the presence of BNDES credit lines and (ii) the possibility to trade carbon credits.

The sensitivity analysis results showed that the wind speed, the selling price of energy, and disbursement for the investment are the variables that have the most significant impact on the NPV. These results highlight the importance of auctions to reduce uncertainty, since the long-term contracts and the fixed portion for the energy produced remuneration directly affect the project's cash flow generation.

The wind farm project is likely to have higher feasibility in all analyzed scenarios: 96.36%, 97.70%, and 98.50% in ACL for scenarios A, B, and C, respectively. In ACR, the values are 85.02%, 99.04%, and 99.58% for scenarios A, B, and C, respectively. This reveals that the probability of a project being viable is higher in the ACR. Consequently, this environment provides greater financial security to the investor.

The Levene's test results confirm that the ACR is less risky for the producer than the ACL, since there is a statistically significant difference in NPV variances for all scenarios (p-value = 0.000). However, in the ACR, funding is critical to reducing risk, since there are statistically significant differences (p-values = 0.004) between NPV variances for scenarios A and B. However, although ACL provides greater risk, it can potentially generate higher returns.

Table 9
A comparative analysis of producer's risk in different scenarios.

Scenario	P-value (ACL)	P-value (ACR)
A × B	0.561	**0.004**
A × C	0.740	**0.000**
B × C	0.794	0.226

*Values in bold represent statistical significance.

In the scenario that considers the project participation in CDM, we concluded that the additional revenues from carbon credit trading can increase producer revenue, but minimally contribute to reducing the risk of investment failure. The mean of NPV was US$ 41,744,591.75 and US$ 43,182,768.39 in ACL for scenarios B and C, respectively, and the mean of NPV was US$ 14,729,251.27 and US$ 15,781,463.28 in ACR for scenarios B and C, respectively. However, when comparing the scenarios B and C, there were no statistically significant differences (p-values equal to 0.794 and 0.226 in ACL and ACR, respectively) between NPV variances, proving that carbon credit trading is not a suitable policy to provide financial security to renewable energy producers.

These results also indicate that to attract new investors in wind power generation, the ACR auctions and BNDES financing have an important role to reduce the financial risks of wind energy producers in Brazil and have been important to leverage the growth of wind power in the country. Finally, the results show the importance of regulatory strategies and incentive mechanisms to support RES growth, which are not yet economically competitive compared with conventional energy sources.

Conflicts of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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