Switch Option for Wind Farms: Mining Cryptocurrencies

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Abstract

Rules for long-term energy supply auction in Brazil establish that new power plants must supply their contracted energy a fixed period of years after winning a sealed bid reverse auction. If this period is long and the construction period is short, as occurs in the case of wind farms, the firm has the option to build the plant ahead of schedule and sell the energy produced in the open market. We analyze the case of a wind farm that is required to supply its energy to the regulated market in 6 years' time, which chooses to begin construction immediately in order to sell its energy in the electricity spot market for four years after the two-year construction period.

On the other hand, by doing this the firm becomes exposed to price volatility which may have a negative effect on the returns of the investment. To mitigate this risk, we consider the case where the firm, in addition to the wind farm, also invests in a cryptocurrency mining facility. This has the effect of creating an option to switch between selling energy of mining Bitcoins. In order to determine the value of this strategy, we model these two highly volatile stochastic variables, energy and Bitcoin prices, under distinct stochastic processes. The results suggest that not only does the anticipation of the investment in plant construction create value to the firm, but that the option to switch output between electricity and Bitcoin significantly increases this value, although it also increases the risk.

Keywords: real options, switch option, renewable energy production, cryptocurrency mining

1 Introduction

The Brazilian Electricity Regulatory Agency (ANEEL) regulates the future supply of energy in the country by means of reverse energy supply auctions for different electricity generation sources. The auction determines the long term rate the firm will receive from the sale of energy. For energy supply planning purposes, and given that the power plant still needs to be constructed, the starting date for energy delivery is typically set a few years in the future. For example, in a A - 6 auction, the firm will have up to 6 years to build the plant after which it must supply the contracted amount of energy for the duration of the concession. The concession period varies depending on whether the energy source is hydraulic, thermal, or renewable (solar, wind or biomass).

Considering an A - 6 contract for a wind farm where the plant could be constructed in two years, the firm may choose chooses to anticipate the implementation of the site. If it does so, it will have up to 4 years in which to sell its energy production to a third party in the free, unregulated market. The construction of the site ahead of schedule is an option that if exercised, allows the firm to sell its energy output at the spot prices, which is Price for Settlement of Difference (PLD). This price is determined by Chamber of Electric Energy Commercialization (CCEE) on a weekly basis as a function of energy demand in the integrated national grid (SIN). On the other hand, electricity spot prices are highly volatile, and PLD could be so low at times that direct energy sales in the free market may not provide sufficient incentive to anticipate the construction of the plant.

In this paper we suggest that this problem can be mitigated if, in addition to anticipating construction of the wind farm, the firm also invests in an energy intensive cryptocurrency mining facility which would allow it to optimally choose between energy sales of bitcoin revenues depending on energy prices.

Cryptocurrency mining is an operation that requires specialized hardware which may or may not be suitable for other uses, and consumes electric energy as its main input (Tschorsch & Scheuermann, 2016). It represents a crucial part of the creation and maintenance of a digital coin, or cryptocurrency. A cryptocurrency is a token pertaining to a digital ledger that uses cryptography in association with consensus algorithms to create a secure layer for messaging and value transactions. The production and ownership of cryptocurrency is legal in Brazil for individuals and organizations alike, providing proper fiscal support.

This paper is organized as follows. In the next section we provide an analysis of wind energy generation in Brazil, of cryptocurrency mining, as well as a brief review of the Blockchain technology. The third section discusses the stochastic modeling of the price series of Bitcoin and of the PLD in Brazil. The fourth section presents the simulation model used to determine the value of the option to switch between cryptocurrency mining and selling electric energy in the open market and present some results. In the final section we conclude and discuss limitations and suggest improvements to this work.

2 Flexibility in the Energy sector in Brazil

2.1 Regulated and non-regulated energy markets

Brazil's regulatory space is considered to be favorable to wind farm construction. The country has large wind power production capacity and due to the relatively short time required to build a wind farm compared to other sources of energy, these unit have been favored by the energy regulatory agencies.

Recent wind power auctions showed increased private sector interest and participation with power producing capacity surpassing the demand. Yet many international players did not participate, mainly due to regulatory uncertainties.

After the energy supply crisis in 2001/2 and the failure of the first wholesale energy market (MAE), the government created a new regulatory environment for the wholesale regulated market (ACR) by means of auctions between producers and distributors, and a free market (ACL) between producers and big consumers with demand greater than 3MW. In 2004 an auction system was created in the ACR environment, and in 2008 this mechanism was extended to Reserve Energy contracts in order to increase the energy supply security of the Brazilian Electricity System (SIN). The auctions have been mostly for the supply of renewable energy sources.

Auctions to purchase energy specifically from new (unbuilt) power plants have a period of years previous to the delivery date where the power plant can be built. If the plant is ready ahead of time it is then allowed to sell energy in the free market. Those periods vary, in accordance with the needs of the regulators, from 3 years (A-3, the most recent being in 2015), 4 years (A-4, the most recent being in 2018), five years (A-5, the most recent being in 2016) and six years (A-6, the most recent being in 2018).

2.2 Real Options in the Energy Sector

The theory of Real Option uses the same mathematical insights originally developed by Black and Scholes (1973) and Merton (1973) for the pricing of financial derivatives. A financial option is a derivative that reflects in its price the value of the choice which is given to its buyer. The value of the opportunity to choose whether to take or not an action was for many years an elusive pursuit in financial markets and it is still overlooked in many real investment projects.

Investment projects are usually priced with the Discounted Cash Flow method, using the Net Present Value (NPV) or the Internal Rate of Return (IRR) criteria. These measures, though undoubtedly useful, fail to capture the value of managerial flexibility of real world decisions, such as deciding whether to anticipate the construction of a new plant or waiting for new information to decide on the best operating strategy to follow. Given that these flexibilities can be modeled as options on real assets, option-pricing methods must he used for their valuation.

The use of financial options models to options on real assets and projects laid the basis for the Real Options approach. The same fundamental variables are used, namely the underlying asset value, the strike price, the expiration date of the option, the volatility of the underlying asset, the risk-free discount rate for the duration of the option and the dividend, or cash flow, distributions.

Real options can be useful to evaluate project that present significant uncertainty and flexibility for managers to take action as new information is received. Another important characteristic is the irreversibility of the investment (Dixit & Pindyck, 1994).

An extensive review of renewable energy projects with real options valuation, as well as a brief review of real option literature, can be found in the work published by Kozlova (2017). Based on that classification, this present work utilizes the price of electricity and price of alternative output as uncertainties, the latter modeled with a geometric Brownian motion (GBM) and the first with a mean reverting process (MRP). A switch option type was chosen, and while this choice is uncommon in wind power research, this can be explained by the novelty use of cryptocurrency mining as an alternative output. So far as we have knowledge, no work has been done with this scope.

2.3 Cryptocurrencies

A long-sought-after problem in computer science was a way to confer intrinsic value to a digital code so that it could behave as a mean of exchange. One relevant thought experiment on this subject was proposed by Nick Szabo in a blog post concerning a BitGold token (Szabo, 2005) and references to this idea can be traced back to the work of David Chaum starting from 1982 (Chaum, 1982). The main concept is the ability to use communication infrastructure to transmit real value from person to person without the need of a trust-lending partner or intermediary.

Advances in cryptography based on the work of Diffie and Hellman (1976) enabled the use of digital signatures to hide content of messages being distributed in public channels or to prove ownership and authenticity of signed documents. Those advances fueled the research for secure communication exchange.

The Proof-of-Work technology, specifically the technology denominated Hashcash (Back, 2002), associated with an incentive driven consensus algorithm laid the basis to the development of the first peer-to-peer electronic payment system known as Bitcoin, first deployed in the year of 2009. Bitcoin network provides a layer for direct transactions between participants with no information about each other. The currency being exchanged in the network has volatile value, determined by individuals trading in specialized online exchanges.

To participate directly in the network a gratuitous version of the Bitcoin client must be downloaded from a central repository[1] and executed in personal computers or specialized hardware. Documentation on how to install the client is readily available and constantly updated by developers. Indirect participation on the network is possible through the use of relay software that communicates with a Bitcoin full node.

Participants on the network may wish to contribute to the Proof-of-Work mechanics by applying a hash function on blocks of unsettled transactions. The hash function produces a fixed length and unique string of characters from a given input but it is not possible to predict the outcome without actually using the function, which means that given a desired result the Proof-of-Work is a trial and error, computational intensive process.

The Proof-of-Work algorithm used in Bitcoin demands a predetermined number of leading zeros in the output of the hash function – the difficulty of the hashing operation increases exponentially the more leading zeros are expected. Anyone can participate in the process – which demands only to be connected to the network to receive the appropriate input and have an equipment capable of applying the hash function – but network difficulty has increased continuously because of hardware fabricated with the sole purpose of calculating hashes. Those devices are denominated mining hardware, as the participation in the Proof-of-Work alludes to the the work of a gold miner (Nakamoto, 2008).

Miners, as are denominated the participants that contribute to the Proof-of-Work, receive new units of the currency used in the Bitcoin network, also known as Bitcoins. The difficulty of the network is dynamically adjusted so that each new successful Proof-of-Work solution, which creates a block of aggregated transactions in the global ledger, is found at ten minutes interval in average. The reward paid to the miners is halved every 210,000 blocks, or about four years, starting from 50 Bitcoins per block in 2009 (currently at 12.5 from 2017 on). The daily rate of Bitcoins received is directly dependent on the hashing capacity of the equipment used by the miners. The main cost of Bitcoin mining, besides the mining hardware, is electric energy consumption (Antonopoulos, 2014).

The transactions arranged in blocks constitute the Blockchain technology, since blocks are linked or chained to their predecessors through a digital signature. One of the proposed benefits of Blockchain technology is that, because there is no central authority to verify every transaction, there is no single point of failure or network clog. Verification is handled in a decentralized consensus obtained through the protocol of building, mining and verifying each block.

Other advantage of using Blockchain consensus is that because Proof-of-Work requires actual computations and since every block is signed and verified by each successor the result is a distributed ledger that is very costly to be tampered with. Blockchain technology is thus seen as a promising new development, and Bitcoin is regarded as one of its flagships, though not it’s only viable implementation.

The current Proof-of-Work infrastructure rely heavily in electric energy, and cheap energy is a determinant to mining profitability (Krause, 2018). Energy consumption by the Bitcoin network is at 3.4 Gigawatts on the first half of 2018. Besides raw power, another important factor is heat dispersion, as the mining hardware produces considerable heat. This is mitigated by building mining facilities in naturally cold environments or by the use of cooling infrastructure which further increase power consumption.

3 Model

3.1 Anticipating site construction and switch option

The main objective of this paper is to appraise the financial value for a Wind Farm project in North East Brazil, who is bound to enter service in 6 years from the present, that can anticipate the construction of the site and sell its available energy in the free market, up to the moment where it has to provide its contracted capacity to the grid in the regulated market. Alternatively, once the farm is in place, it can also use its energy supply to power a private venture intensive in energy use, for the available time until it is bound to the regulated market. We will model this venture as a cryptocurrency mining facility, specifically a Bitcoin plant. If the Wind farm chooses to build the mining plant, it can choose, in every time period to either sell energy in the free market at the PLD price or alternatively power the mining facility and farm Bitcoins which are valued in US dollars.

We assume that the wind farm plant can be fired up in 24 months after the start of construction. Therefore, with a: A - 6 years contract, it could operate freely during up to 4 years. We also assume that a corresponding blockchain mining plant can be put together in 4 month time, and operate for 24 months (2 years) after which time its hardware will be outdated and also depreciated, with no resale value. For the wind farm, the cost related to the anticipation project is equivalent to the Capital Expenditure in year 4 (start the farm in 6 years minus 2 years of construction), minus this same value in present value at the effective start of construction considering the anticipation. If the mining facility is implemented, the depreciation to be considered will be the sum of the wind farm depreciation, which depreciates continuously for the anticipation time plus the regulated concession span, plus that of the mining facility, which depreciates in two years’ time.

We assume the concessionaire will begin construction of the wind farm immediately at time 0, and put together a mining facility to operate in years 3 and 4, after which time it can reinvest in a new set of hardware to operate the mining facility for another 2 years (5 and 6).

As the wind regimes of the North East of the country, which is the most favored region for wind farming, are seasonal and more intense in the winter months, making them complementary to the raining period, we will assume a deterministic seasonal regime for the power output of the wind farm based on Lira, Moita Neto, Loiola, Silva, and Alves (2017). In the regulated market the generator is limited to its assured capacity in the contract, but during the anticipation period the power generator is free to use all of its output. Also the mining facility capacity will not be able to use the full output of the farm since it is situated in a high temperature region and part of the output must be used for refrigeration of the operating facility, different from other mining regions such as Iceland where the natural temperature is enough to refrigerate the unit which is highly endothermal.

3.2 Modelling Bitcoin Price

Bitcoin price series are available from as early as 2010 at online exchanges around the world. Cryptocurrencies, such as Bitcoin, are traded continuously around the globe, 24 x 7, without weekend or holyday stoppage. Aggregate price series exist and as of the date of this writing are easily found without charge. Although highly volatile, as last year's performance shows, Bitcoin market capitalization has been continuously growing attaining 125 billion USD as of Dec 2018. The series used to build a model for price forecast were obtained from cryptocompare.org website, downloading data with *R* language script which allows for the download of up to 2,000 daily observations.

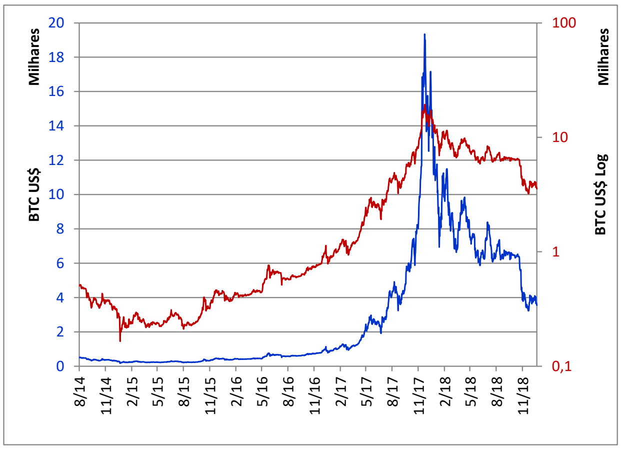

Figure 1 – Bitcoin price from August 2014 to Jan 2019 (Log_{10} scale on right side)

To minimize the impact of exponential gains of the last several years a shorter series of 1,600 daily observations was used, starting in August 2014 up until the end of December 2018. The one-step difference of the series was obtained and the resulting series was log transformed. These are displayed in Figure 1 in historical value and in $\log_{10}$ scale. Although the exponential valuation is evident over the time span, it also becomes apparent that the drop in value in 2018 had already happened in 2014-2015 in almost the same magnitude.

3.3 Modelling Bitcoin Mining Difficulty

Bitcoin mining revolves around a trial and error process and calculation of the outputs are best expressed by averages. Mining refers to the process of guessing a correct input for a pre-determined SHA256 hash output format. The output of a SHA256 hash is always a 256 bit number and it is not possible to reverse engineer the hash function to obtain an input starting from the output. Although the result of a hash is deterministic, and is the same every time for the same input, there is no way of knowing the result other than applying the hash function over the input, as no information from the input is preserved in the output.

To successfully mine a block, the mining hardware must gather a set of data in the format of a block header and transactions and apply the hash function over it using a variable field named nonce as a random seed. If the hash result is a number which is less than the network difficulty target then the mined block is deemed fit and is sent forward for validation and annexation on the Blockchain history. Only after finding a suitable block and receiving validation from the network can the miner claim the block reward in Bitcoins.

The mining process is therefore dependent on the mining hardware´s the capacity to generate hashes. In the minimum difficulty settings (Bitcoin network difficulty = 1, as seen in the early days of the currency) the amount of hashes needed for the whole network to continuously produce a valid block in a ten-minute average interval was approximately 7M Hashes per second (H/S).

The network difficulty is determinant in those calculations and it is not a fixed constant. It is recalculated every 2016 blocks, or about every two weeks, and takes in consideration the hash power of the previous period to maintain the block generation time to 10 minutes. Because of this automatic difficulty adjustment, Bitcoin mining should have very narrow margins and the profitability is mostly dependent on the price of electricity. Therefore the income of a mining farm is not only dependent of the price of Bitcoin, but on the ratio of this price divided by the difficulty in Hashrate to produce one Bitcoin. Figure 2 shows the variation of the ratio BTC $ / Hashrate mining difficulty for the last 4 years.

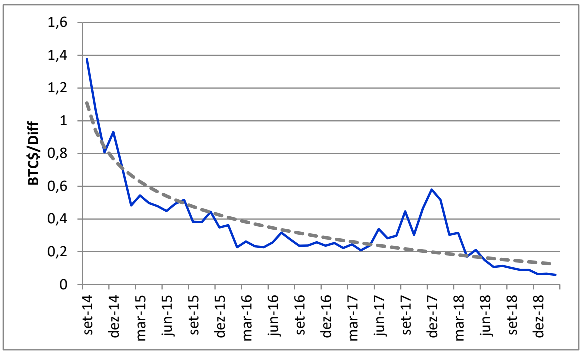

Figure 2 – Average monthly Bitcoin monthly price (US$) / hash rate difficulty

As we need to model BTC$/Difficulty for the model to be used, it is essential to determine also which stochastic model should be used for this time series modeling. To model this ratio we ran an ADF test with intercept and trend on the log of these monthly series and obtained a value of t-statistic of: -2.32805, not rejecting a unit root at 10% level. Likewise a Variance ratio test also did not stabilize bellow 1. So, again, we have a strong indication of a GBM diffusion process.

The Geometric Brownian Motion (GBM) diffusion process has the differential equation displayed in equation (1).

$$dB = \mu B dt + \sigma B dz \qquad (1)$$

Where B is the Bitcoin/Hashrate Ratio to be modeled, μ is the drift parameter, σ the volatility parameter, dt the time increment, and dz the standard Weiner process. The simulation equation for the price B rate is given in (2).

$$B_t = B_{t-1} e^{\left(\mu - \sigma^2/2\right)\Delta t + \sigma\sqrt{\Delta t} \times N(0;1)} \qquad (2)$$

We calculated the parameter values in monthly values and these are displayed in Table 1.

Table 1 – GBM parameters for BTC/Hash Rate modeling

	Month	Year equivalent
μ	-5.2%	-62.4%
σ	23.9%	82.8%

As this variable is not traded and although we have a historical track, it is difficult to assume a drift parameter as that of Table 1 (-5.2% per month). Theoretically such a variable should be driven exclusively by its volatility parameter which is also extremely high (23.9% per month).

Therefore, we will assume in our model two propositions: a first one with a more parsimonious monthly drift value of μ: -2%, instead of the above, and a second one with a drift o zero: μ: 0%, in order to reflect the supposition made above.

3.4 Modelling Electricity (PLD) Price

Weekly series of spot energy prices (PLD) are available for the North Eastern region of Brazil, since most Wind farms are located in this sub-region, between January 2000 and December 2018, as informed by the Brazilian Electrical Energy Clearing Chamber (CCEE) in US$ / MW. These are displayed in Figure 3.

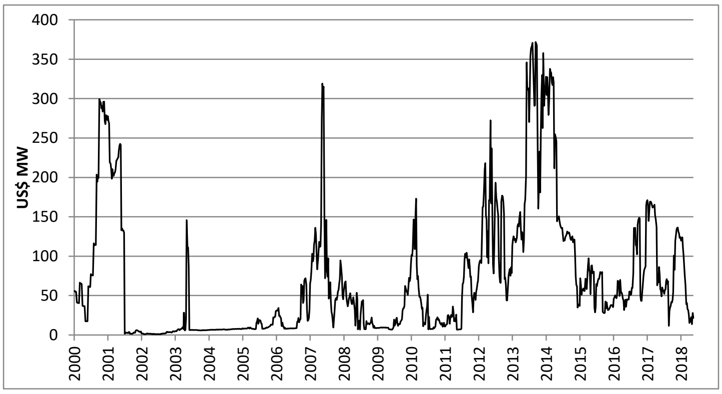

Figure 3 – PLD energy prices for NE region of Brazil

As we need to model PLD prices for the model to be used, it is essential to first determine which stochastic model should be used. We first run an Augmented Dickey-Fuller (ADF) test with intercept and trend on the log of the series displayed. The t-Statistic obtained is: -4.154976, which rejects the presence of a unit root even at 1% level (-3.967667) for this number of samples. Therefore, we have a strong indication of a Mean Reversion Model diffusion.

In order to confirm the presence of mean reversion, we ran a Variance Ratio test, on the log of the series. As the value of the Variance Ratio for PLD rapidly drops below 1 converging to values below 0.1 after 300 days, we have confirmation of the presence of a mean reversion for this time series.

Therefore, the energy price of PLD was modeled as a Geometric Mean Reversion (GMR) diffusion process, as proposed by Schwartz (1997), and shown in Equation (3):

$$dP = \eta\left(\ln \bar{P} - \ln P\right)Pdt + \sigma_P Pdz \qquad (3)$$

where η is the mean reversion coefficient parameter of the process; σ_P is the volatility of the PLD price, $\bar{P}$ the mean or equilibrium level of the PLD price, and dz is the standard Weiner increment.

In order to calibrate these parameters, we used the approach described by Dias, Bastian-Pinto, Brandão, and Gomes (2011). But it is apparent in the series displayed in Figure 3 that the mean level of prices has changed in the time span displayed. Since 2007 a lack of regular rainfall has drained the reservoirs of south east region of Brazil as well as those of the north eastern region, where most of the wind farms are located. The hydro capacity of the country is still by far, the main energy supplier of the country, counting around 80% of the whole energy generation installed capacity. This has led to an increase in non-regulated energy prices, as can be observed. Therefore, we chose to calibrate the proposed model using a time span from July 2007 to present, in order to better model the expectation of future energy prices.

As defined in Dias et al. (2011) the risk neutral simulation for this stochastic process is (4).

$$P_t = \exp\left\{ \ln\left[P_{t-1}\right] e^{-\eta\Delta t} + \left[\ln\left(\bar{P}\right) - \frac{\sigma^2}{2\eta} - \Pi\right]\left(1 - e^{-\eta\Delta t}\right) + \sigma\sqrt{\frac{1-e^{-2\eta\Delta t}}{2\eta}} N\left(0,1\right)\right\} \tag{4}$$

Where Π is the risk neutral adjustment that will be determined by a numerical approach, to be described latter on, and Δt the time increment to be used in the regression. If we consider a year to be Δt=1, then, for a monthly increment: Δt=1/12, a weekly increment: Δt=1/52 and a daily increment: Δt=1/365. Simulations in this paper will be performed for monthly periods of Cash Flows.

According to Dias et al. (2011) all other parameters were calibrated from the log of the PLD time series, by running the regression (5).

$$\ln\left(P_t / P_{t-1}\right) = \underbrace{\left(1 - e^{-\eta\Delta t}\right)\left(\ln \bar{P} - \sigma^2/2\eta\right)}_{a} + \underbrace{\left(e^{-\eta\Delta t} - 1\right)}_{b-1} \ln P_{t-1} \tag{5}$$

Parameters are defined by (6), (7) and (8).

$$\eta = -\ln(b)/\Delta t \quad (6); \quad \sigma = \sigma_\varepsilon \sqrt{\frac{2\ln b}{(b^2-1)\Delta t}} \quad (7); \quad \bar{P} = \exp\left[\left(a + \frac{\sigma_\varepsilon^{\,2}}{2\left(1+b\right)}\right)\Big/\left(1-b\right)\right] \quad (8)$$

Where σ_ε is the standard error of the regression.

Therefore we use this value as the equilibrium mean of the process. Table 2 displays the values thus obtained. Values are calculated from weekly observations, but are also given in monthly (which will be used for the model) and yearly values for reference as of its magnitudes.

The initial value, at t_0, for the simulation of the PLD time series is the last value of the PLD displayed in Figure 3: P_o = 20.00 US$/MW. We will also consider the regulatory cap for PLD price, which stands at the time of this research at: P_{max} = 180 US$/MW, as an upper limit for simulation of PLD prices.

Table 2- Parameters for the MRM model for PLD

	Week	Month	Year
η	0.0503	0.2178	2.6135
σ	32.1%	66.8%	231.3%
PLD $\bar{P}$		79.29 USD/MW	
P_{max}		180 US$/MW	

3.5 Cash Flow and Investment Structure of the Cases Modeled

The basic case in this paper is the anticipation of the wind farm site construction. We use the data developed in Fontanet (2012) who models a typical wind farm in Brazil with conditions similar to the one in this study. These are listed in Table 3.

Table 3 – Wind Farm Specifications

	Assured	Nominal
Capacity (monthly output)	3,577 MW	7,154 MW
CAPEX (US$)	9,540,000.00 US$	
Monthly depreciation	40,000 US$	
Weighted Average Cost of Capital WACC	8% (year)	0.64% (month)
Risk Free rate	5% (year)	0.54% (month)

In the case of anticipation of the wind farm construction, the Capital Expenditure to be considered is the value in Table 3, minus this same value discounted at the corresponding WACC, for the time frame of the anticipation: either 2 years or 4 years, depending on the scenario. This amounts to US$ 2,528,287 for 4 years anticipation of construction.

The normal operation of the Wind Farm, under the regulated market in a A minus 6 years grant, is described in Figure 4.

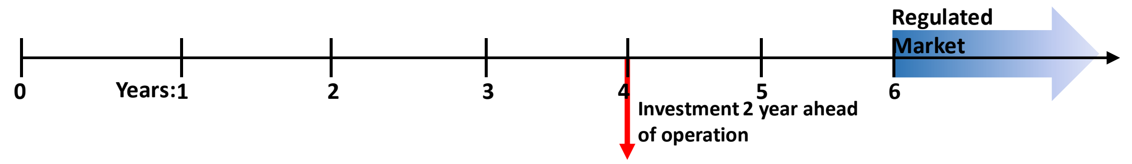

Figure 4 – Wind Farm A minus 6 years operation in the regulated market

The scenario of 4 years construction anticipation is shown in Figure 5.

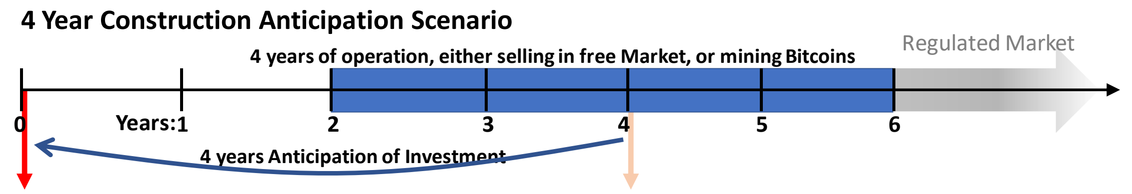

Figure 5 - Scenario of construction anticipation

We also consider that when selling energy to the free market, the plant can commercialize up to its full capacity, but this will be limited to the wind regime in the region, which is describe by Lira *et al (2017)* and is shown in Figure 6, when we consider the average of generation subject to the wind speed regime.

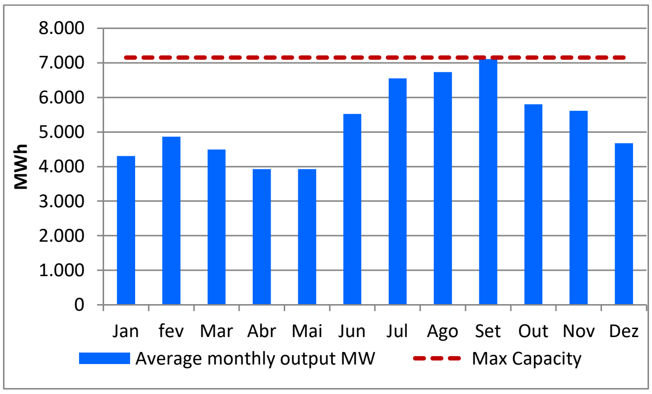

Figure 6 – Wind Farm monthly output

In the case of only energy sale to the free market (PLD), the constructor will earn the following monthly Cash Flow as in (9).

$$EECF_t = (PLD_t \text{ x } Output_t \text{ x } 0.86 - \text{Depreciation}) \text{ x } (1\text{-T}) + \text{Depreciation} \qquad (9)$$

Where:

$EECF_t$: Cash Flow from Energy Sale in month t
PLD_t: Energy price in t (stochastic and modeled with (4)
$Output_t$: Energy seasonal monthly production as in Figure 6
T: applicable income tax rate (34% In Brazil)

A value of 14% is considered as variable costs on income (taxes, fares and others).

$EECF_t$ will be earned by the constructor for 48 consecutive months after the construction period of 24 months.

3.6 Switch option when mining Cryptocurrencies

Once the wind farm is in place and producing energy, the constructor has the possibility on investing in a Bitcoin mining plant that uses the wind farm energy output. Data for this mining plant are listed in Table 4.

Table 4 – Mining plant specifications

Cost of mining unit	700 US$
N. of mining units	3,400
CAPEX (US$)	2,325,000.00 US$
Total Monthly depreciation (wind farm + mining plant)	140,000.00 US$

The constructor can at this point choose to mine Bitcoins, which will earn him the cash flow as in (10).

$$BCCF_t = (B_t \text{ x } Output_t \text{ x } 0.86 - \text{Tot Deprec.}) \text{ x } (1\text{-T}) + \text{Tot Deprec.} \qquad (10)$$

With: $BCCF_t$: Cash Flow from Bitcoin Sale in month t

B_t: BTC Price / Hash Rate Difficulty in *t* (stochastic and modeled with (2))

It takes 3 months for the constructor to put together the mining plant, and as it has to be in place at the start of the wing farm operation, this investment must take place in month 22 as the wind farm will fire up in month 25.

Now the constructor has a switch option to choose between cash flows generated by (9) or by (10), where in both cases the depreciation is that of Table 4. Also in both possibilities of cash flow the CAPEX of the mining plant is considered.

4 Results

4.1 Wind Farm construction anticipation and sale to free market

In this topic we only consider selling of the energy generated at the PLD price for the anticipation of the wind farm in both scenarios. These values will be used as reference for comparison with the results from the Switch Option scenarios. As mentioned, the values of CAPEX are the present value of the original investment to be spent in year 0 of the original project under the [A minus 6] contract, minus the same amount discounted at the WACC rate to the start of the anticipation scenarios. After 24 months of the investment, the constructor will receive the cash flows described in (10). As there is no option in this case, the cash flows are discounted at the WACC rate, and PLD is modeled by (4). Therefore, there is no need to consider the risk premium Π in this equation. We estimate the present value of this cases using Monte Carlo Simulation, in order to have a distribution of Net Present Values (NPV) results and compare these to the ones to be obtained from the scenarios with the switch options. These are displayed in Figure 7.

From this simulation two aspects can be clearly pointed out: construction anticipation shows positive and strong NPVs. A 4-year anticipation will yield a NPV of US$ 2,655,717 and with a 13.3% probability of a negative value. This result is 105% of the net investment required to earn it, which not only indicates a significant return but also a relative low risk associated to it. And this last aspect is contrary to our previous expectations, which assumed that the risk in being exposed to the volatile PLD price dynamic would drive off constructors from such an anticipation project. After all, it's because of this price volatility that the regulated market was put together.

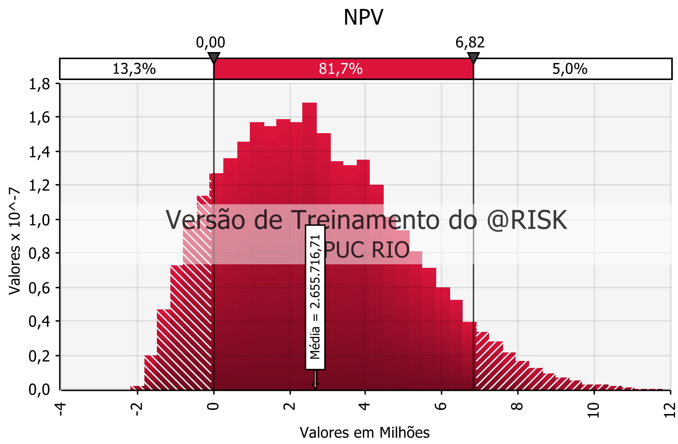

Figure 7 – NPV distribution for 4 years anticipation of energy sale

4.2 Construction anticipation and Switch Option between energy and Bitcoin sale

Now we consider two scenarios for mining facility implementation, once the construction has been anticipated. The constructor can implement a mining facility with the characteristics listed in Table 4 in month 22 for operation start in month 25. In this case the investment in the facility will be undertaken 3 months before the wind farm can be fired up. As the mining plants operational life runs out after 2 years, if the constructor decides to continue mining, he must invest in a new plant of the same value, in month 46 for start of mining operations in month 49. This is scenario one: 4 years of Bitcoin mining. But as Figure 2 shows, income from mining activity has been decreasing rapidly and may not be rewarding anymore 4 years from now. Therefore, the constructor may decide not to renew his mining facility investment after 4 years and only operate it for the first plant. We call this scenario two: only 2 years of Bitcoin mining.

In both cases we consider the risk premium Π for both stochastic variables: PLD price and Bitcoin price. In a first approach we use a drift value of μ: -2%, as explained in chapter 3.3. Again we estimate the present value of this cases using Monte Carlo Simulation, in order to have a distribution of Net Present Values (NPV) results and compare these to the ones to be obtained from the scenarios without the switch options. These are displayed in Figure 8.

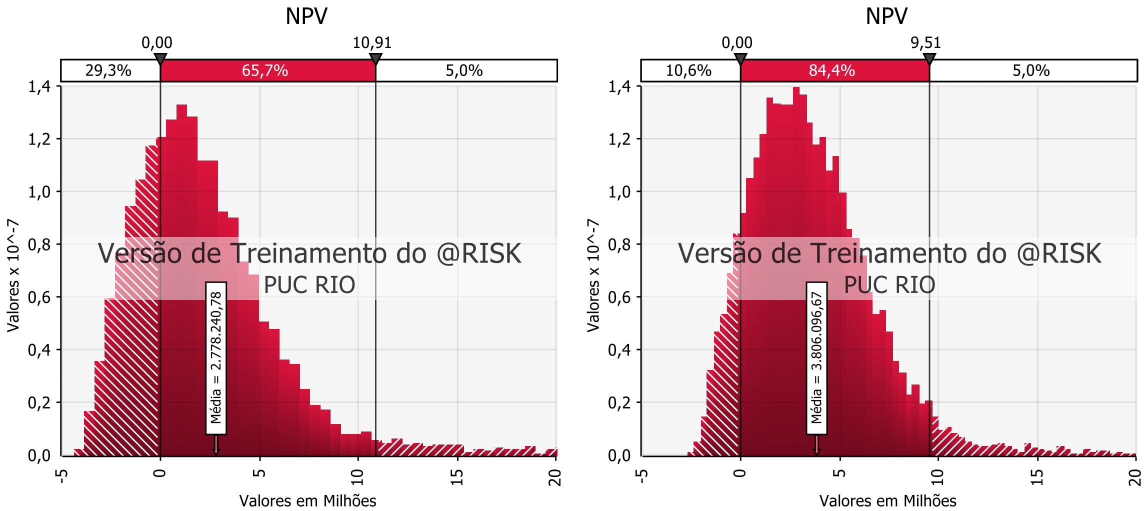

Figure 8 - NPV distribution for 4 years (left) and 2 years (right) scenarios of Switch option PLD x Bitcoin, with drift rate for the BTC$/Diff ratio μ: -2%

NPV of scenario 1 (4 years of Bitcoin mining) is US$ 2,778,241, thus only an increment of 4.6% over the base case (anticipation of wind farm construction), with a probability of negative NPV increase to 29.3% (from 13.3%). Therefore, a slight increase in return for a major increase in risk. But the scenario 2 (only 2 years of bitcoin mining) is US$ 3,806,097 an increment of 43.3% over the base case, with a probability of negative NPV of 10.6%. This indicates that being able to mine bitcoins for only two years is highly rewarding and reduces risk, as well as having the option not to renew the mining investment for a second 2 years turn.

Now we run the same simulations using a null drift value for the BTC$/Diff ratio ($\mu$: 0%), also as pointed out in chapter 3.3. The same results are displayed in Figure 9.

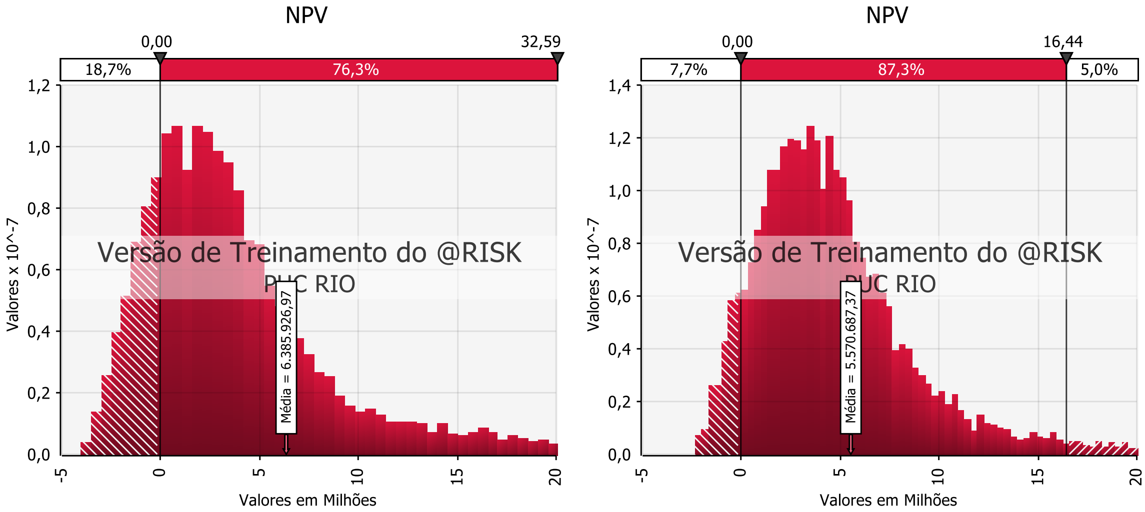

Figure 9 - NPV distribution for 4 years (left) and 2 years (right) scenarios of Switch option PLD x Bitcoin, with null drift rate for the BTC$/Diff ratio μ: 0%

Again, from these simulations two aspects can be clearly pointed out: both scenarios of switch option show positive and strong NPVs. While the 2 years switch option yields a NPV of US$ 5,570,687, with a 109.8% increase over the PLD only sale scenario, and a 7.7% probability of having a negative value, the 4 year switch option will yield a NPV of US$ 6,385.927, with a 140.5% increase over the PLD only sale scenario, and a 18.7% probability of having a negative value. These results yield a significant result increase over the base case in both scenarios of construction anticipation. All results are summarized in Table 5.

Table 5 – Results Summary

	NPV (US$ M)	*Prob % of negative NPV*	*NPV Increase over Base Case*	*NPV Increase Scenario 2 over 1*
Base Case -Wind construction 4 year anticipation	2,656	13.3%		
Bitcoin mining for 4 years – with BTC$/Diff drift of μ: -2%	2,778	29.3%	4.6%	
Bitcoin mining for 2 years – with BTC$/Diff drift of μ: -2%	3,806	10.6%	43.3%	
Bitcoin mining for 4 years – with BTC$/Diff drift of μ: 0%	6,386	2.3%	140.5%	129.9%
Bitcoin mining for 2 years – with BTC$/Diff drift of μ: 0%	5,571	7,7%	109.8%	46.4%

5 Conclusions

Although this work is theoretical, and it is not a complete in-depth analysis of neither a wind power plant or a cryptocurrency mining operation and cashflow, we believe our models reflect the industry to its best approximation and the findings can be extrapolated for real world usage.

The first and foremost conclusion is that power industry, especially intermittent power producers that relies on natural events for source of power, can benefit from hedging excess output with an energy intensive product. Bitcoin was the option of choice because of the simplicity of a mining infrastructure construction and maintenance, but other energy intensive assets could have been used. This switch option increases profitability with low risk increases and can be a support for the construction of new renewable energy sites globally.

In the field of real options, we find noteworthy that even if Bitcoin has great volatility the switch option offers significant gain by diversification with a mostly uncorrelated asset. The lack of correlation is easily understandable when we consider that energy prices are local and Bitcoin prices are global. In other markets more linked to the production of Bitcoin as China this correlation could be greater and the gains lower. On the other hand, if this measure of diversification was to be taken forward then the production of Bitcoins could be made more decentralized and impacts of price correlations would have to be reassessed in future scenarios.

The findings in this paper are directly determined by Brazilian energy policy and suggest that the electricity regulator could achieve more of its goal of construction anticipation by adopting a liberal approach towards the production and sale of cryptocurrency mined by energy generators. This policy suggestion could be extended for other countries with similar legislation and could be used as a model for the development of renewable energy plants.

The market for cryptocurrency is highly speculative and unregulated and we do not recommend that power generators should thread those without proper knowledge. Yet we believe that Blockchain technology has enabled new forms of trade and communication and that all future development coming from this technology is deeply connected with availability of stable energy prices, connecting these two industries at their root.

This work is just a small contribution for the fields of wind farm power generation, cryptocurrency and real options, and we hope that by stablishing this link other works might follow and future papers might overcome our shortcomings.

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