EVALUATION OF INVESTMENTS IN AN ETHANOL PLANT BY MONTE CARLO SIMULATION

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1. Overview

The sugar cane plants in Brazil, in their majority, have a structure with attached distilleries, which allow them to produce ethanol and sugar from the same energetic input, that is the sugar cane crop. In this way, it is possible to decide which fraction of the sugar cane harvest will be destined for each final product, respecting the technical limits of production. Between 2011/2012 and 2014/2015 harvests, for instance, sugar cane plants opted for the maximization of the sugar production, while in 2015/2016 there was a greater commitment to the ethanol production (União da Indústria da Cana-de-Açúcar, 2019). In general, this decision is made according to the prices of each product on the market. Still, there are many uncertainties regarding the prices of ethanol and sugar.

Ethanol production in Brazil is mainly destined to the transport sector as vehicular fuel. In this sector, the main fuels are hydrated ethanol and gasoline C (popularly called ordinary gasoline). The first fuel is the alcohol produced in sugar cane plants, the second is a mixture of anhydrous ethanol (produced after the alcohol dehydration stage) and gasoline A (pure gasoline, not mixed with non-petroleum products). Thus, since gasoline has ethanol in its composition, these fuels are complementary goods.

Besides, since 2003, with the insertion of flex-fuel vehicles in the Brazilian domestic automobile market, the relationship among vehicular fuels has changed. This type of vehicle runs either on gasoline, or on ethanol, or on any mixture of both fuels. Because of this, the increase in the price of one fuel began to imply in an increase in demand for the other. Thus, there has been a substitutive character between gasoline and ethanol since the advent of flex-fuel cars (Cardoso and Bittencourt, 2013; Nappo, 2007; Orellano et al., 2013; Sant'Anna and Albuquerque, 2014; Santos, 2013). Hence, in Brazil, it is possible to say that gasoline and ethanol are both complementary and substitute goods. Therefore, the market uncertainties of the price of ethanol depend on the price of gasoline and sugar as well.

In relation to sugar, because it is a commodity, its price is established considering the aggregate of world supply and demand for this product. Brazil is one of the countries with the highest sugar production, but there are productions in other countries like India, Thailand and China, for example. Moreover, its futures prices are traded on stock exchanges all aroung the world, influencing their market price. Therefore, market price uncertainties depend not only on ethanol, but also on the supply of other sugar-producing countries.

It is also important to highlight that other factors influence the price formation. In the period between 2006 and 2014, there was an interventionist policy in which the government - through Petrobras - did not transmit any increases from the oil prices to the gasoline by means of a tax reduction. In this sense, since gasoline is a substitute good for ethanol, the sugar-energy sector could not pass the increasing cost to the ethanol price. Therefore, this policy implied a major crisis in the sugar-energy sector (Buscarini and Cesca, 2012; Moreira et al., 2014), leading to the closure of more than 96 closed plants in the period between 2008 and 2015 (Ministério de Minas e Energia and Empresa de Pesquisa Energética, 2018). In this way, it can be seen that the financial returns of the plants are influenced not only by market uncertainties in prices, but also by governmental policies that may even harm them.

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In a crisis scenario and with price and market uncertainties, as well as managerial flexibilities of production, there are models for decision-making. These models are consistents according to methodologies criteria for management that indicate the best decision to make. In this paper, the real options valuation methodology will be used along with Monte Carlo simulation. Through this, it is possible to quantify the value of managerial flexibilities, in relation to the production mix of the plants, as described above, unlike other methodologies such as discounted cash flow (DCF), which does not allow quantify such uncertainties and flexibilities (Amram and Kulatilaka, 1999; Bengtsson, 2001; Copeland and Antikarov, 2001; Dias, 2014; Dixit and Pindyck, 1994; Lambrecht, 2017; Johnathan Mun, 2006; Trigeorgis, 1996). Therefore, the objective of this paper is to evaluate the decision-making in a sugar cane plant, quantifying the managerial flexibilities in sugar cane plants by means of real options valuation methodology.

2. The sugar-energy sector: from success to crisis

In the early 2000s, the sugar-energy industry benefited from a number of investments. Among the investments, the introduction of the flex-fuel vehicle in the Brazilian fleet, which runs on both gasoline and ethanol, or a mixture of both. In addition, international companies were attracted to the sector and made investments (Moraes and Zilberman, 2014; Sauer and Leite, 2012; Silva, 2009). As a result, the country consolidated as the world's largest producer of sugar cane. The ethanol production, which had stabilized at around 10 billion liters during the period between 1990/1991 and 2003/2004, reached record levels of 28 billion liters between 2008 and 2010 (União da Indústria da Cana-de-Açúcar, 2019).

However, in the following decade, the ethanol fuel faced poor results. The main causes were (1) government interference in fuel prices to meet the objectives of an anti-inflationary economic policy, (2) adverse weather conditions and low sugar cane crops renewal, (3) global economic crisis of 2008, (4) competition with the sugar (Buscarini and Cesca, 2012; Caldeira Filho, 2012; Nyko et al., 2013).

More specifically, on government interference, the federal government interfered in the prices of oil products between 2006 and 2014 in order to control inflation, due to the positive rises in the price of the oil barrel. Such interferences are a historical feature in the Brazilian fuels sector, both for oil and for sugar cane products (Marjotta-Maistro and Barros, 2003). Although the free market was established for the fuel sector, the interference persisted through price control with Petrobras, since the federal government is the major shareholder of Petrobras, even though the company is publicly traded. Hence, when the oil price rose in the refineries, the government simply reduced its taxes. Therefore, consumers did not feel the effect of high oil prices and inflation was within the government's goal (Cavalcanti, 2011; Cazeiro, 2010).

In addition to the tax reduction, Petrobras also had to incur the costs of increases in the oil price. Not only that, but due to refinery bottlenecks, Brazil could no longer produce enough gasoline, so Petrobras had to import this oil products and sell it cheaper in the domestic market, since it was more expensive in the international market (Accioli and Monteiro, 2013).

As a result, the sugar cane plants could not pass on the ethanol rising costs to retail prices, due to the substitutive nature of the fuels. Thus, the plants started to suffer losses during this anti-inflationary policy in the period from 2006 to 2014. In Figure 1 it is possible to see how real prices (December/2017 as a base value) of gasoline and ethanol fuels between 2001 and 2017. It is notable that from 2006 gasoline became cheaper, and from 2009 onwards it is possible perceive positive shocks in the price of ethanol, making this fuel expensive.

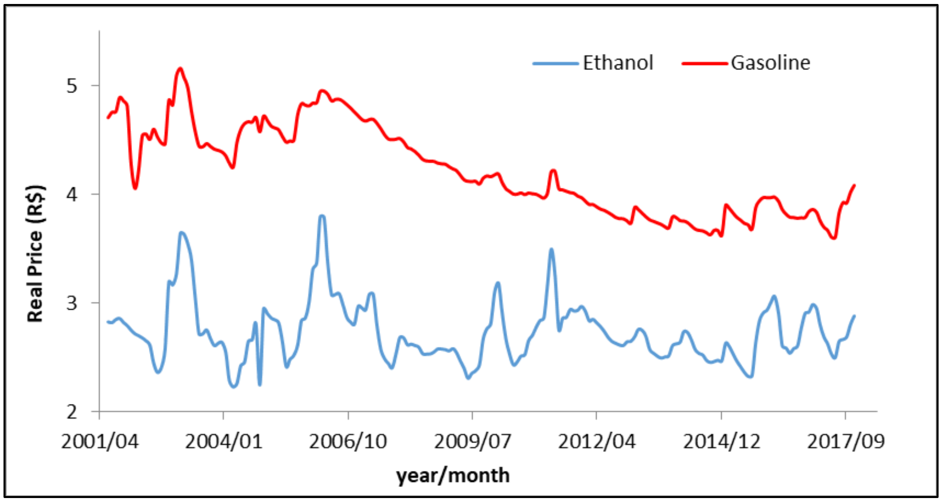

Figure 1 – Vehicular fuels real prices

Source: Author's elaboration with data from ANP (Agência Nacional do Petróleo Gás Natural e Biocombustíveis, 2019a).

Therefore, while the demand for ethanol decreased considerably, the demand for gasoline has grown substantially. Hence, due to refining bottlenecks, Brazil had to start importing this fuel to fill the growing demand. In addition, to ensure the supply of anhydrous ethanol, the government started importing ethanol (Tonin and Tonin, 2014). Moreover, according to Tenkorang (Tenkorang et al., 2015), between 2011 and 2015, the complementary part of ethanol in gasoline increased, that is, it started to produce more anhydrous and less hydrated ethanol in Brazil. In Figure 2 below it is possible to see how the consumption of fuel has change along the recent years.

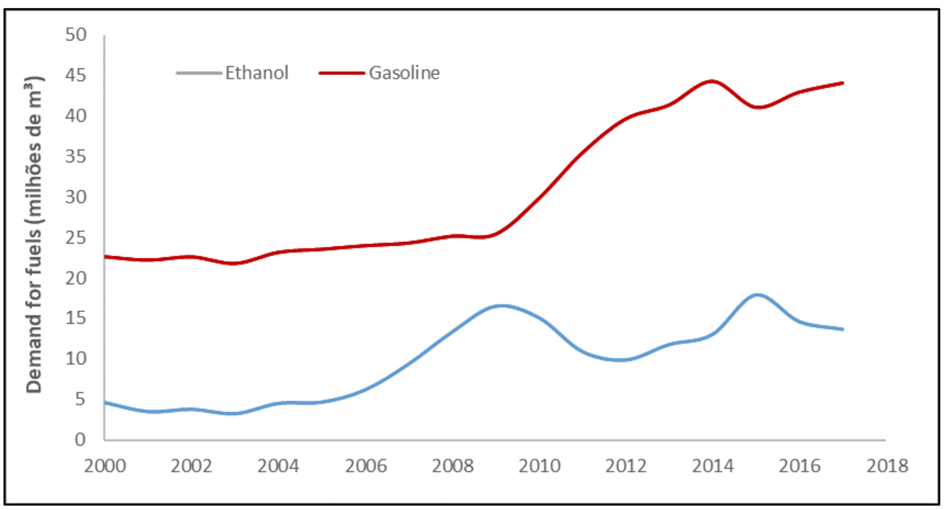

Figure 2 – Vehicular fuel consumption.

Source: Author's elaboration with data from ANP (Agência Nacional do Petróleo Gás Natural e Biocombustíveis, 2019a).

By Figure 2, it is possible to see that in the early 2000s the ethanol demand increased as a result of investments in the sector, flex-fuel vehicle insertion, low prices and higher ethanol production. However, since 2010, there is an increase in gasoline demand and a drop in the demand for ethanol. This is the result of the anti-inflationary pricing policy that made gasoline artificially cheaper. Therefore, with better prices for gasoline, demand for this fuel grew, while ethanol reduced.

Regarding adverse weather conditions, in 2010 and 2011, rainfall was reduced, damaging crops and harvests (Caldeira Filho, 2012). Yet, regarding the inadequate renovation of sugar cane plantations, according to Nyko *et al.* (Nyko et al., 2013), Moraes and Bacchi (Moraes and Bacchi, 2015) there was no adequate renovation of sugar cane plantations, such that their productivity dropped from 115 ton/hectare to 55 ton/hectare. Thus, there was a great loss of agricultural productivity. In addition, with the 2008 crisis, a series of already indebted plants faced serious difficulties of rolling over their debts (Moreira et al., 2014).

Furthermore, there is also competition between sugar and ethanol. Inside the sugar cane plants, for technical reasons, it is possible to define the production mix, i.e., the proportion of the harvest that is destined for the production of sugar and ethanol. Therefore, it is possible to change this mix in small variations, in order to prioritize the production of output or another, according to market prices. In this sense, with the increase in the price of sugar on the international market, production in 2011 reached 38 million tonnes (134% higher than the quantity at the beginning of the previous decade), reducing the volume of sugar cane destined for ethanol production. Then, in 2014, even with the 25% drop in prices, due to the competition between gasoline and ethanol, the volume of sugar produced practically did not change (União da Indústria da Cana-de-Açúcar, 2019). In Figure 3 below it is possible to see the production of both products throughout the 21st century.

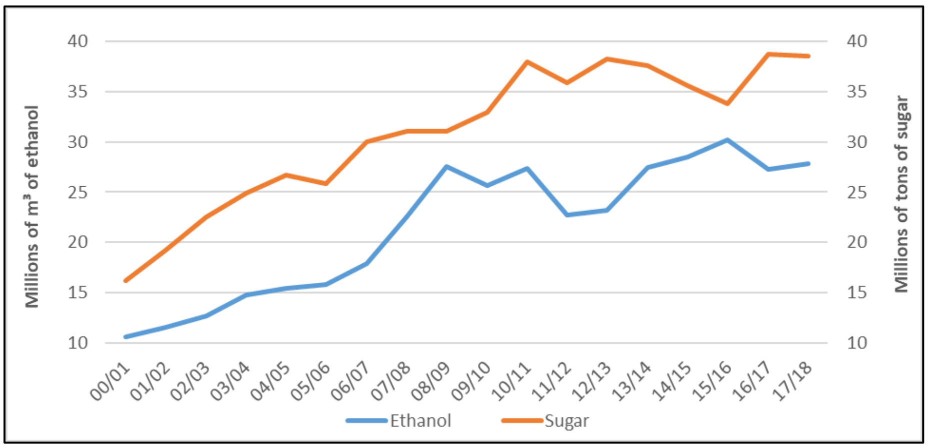

Figure 3 – Sugar and ethanol Brazilian production in 21st century

Source: Author’s elaboration with data from UNICA (União da Indústria da Cana-de-Açúcar, 2019).

It is shown in Figure 3 that until the 08/09 harvest, the production of both sugar and ethanol was increasing similarly. On the other hand, in relation to the last years, it is perceived that the levels of production have opposite directions. If the Pearson correlation is measured between the 00/01 to 07/08 harvest, the value found is 92.73%, while if measured from the 12/13 to 16/17 harvest, the value of the Pearson correlation changes to -75.67%. Therefore, it is possible to conclude that during the investment period of the sugar-energy sector, both products benefited, growing together. However, in the crisis, while production of sugar increased, the ethanol decreased.

The main consequence of the crisis for the sector was the shutdown of 96 sugar cane plants by the end of 2015 (Ministério de Minas e Energia and Empresa de Pesquisa Energética, 2018) due to the factors described above. Those that managed to remain operating were only those that joined into merger processes with international groups (Pinto, 2011).

3. Real Options Valuation in the sugar-energy sector

The assessment of investments by real options valuation (ROV) is made based on three assumptions: (i) irreversibility; (ii) uncertainty; and, (iii) flexibility. About the first, investment decisions are totally or partially irreversibles, for example, a company can define a production contract for fixed quantity and price, such that to reverse this decision there would be a cost to breach the contract. Then, the breach of this contract indicates a partial irreversibility of the decision (Dias, 2014; Dixit and Pindyck, 1994; Trigeorgis, 1996).

Uncertainties can be divided into two groups: (a) economic uncertainties and (b) technical uncertainties. The first type refers to the market oscillations, which are exogenous variables to the project to be evaluated, such as prices, demand, interest rate, etc. The second type are the uncertainties endogenous to the project, for example, for the sugar-energy sector, quality of the sugar cane, quantity of ethanol processed in the distillery, etc. (Dias, 2014).

It occurs that in situations of price uncertainty for a producer, an increase in such prices, coupled with a flexibility of production expansion, add value. Similarly, a drop in sales prices, with another flexibility of a production reduction, or a temporary shutdown option and, in the latter case, an abandonment option, also add value to the project. In this sense, uncertainties and flexibilities add value to the project. Therefore, ROV can be interpreted as an optimization problem, which quantifies the decision-maker's flexibility in altering the project's pre-established course of action at any time, under economic and technical uncertainties, to complement an irreversible investment decision.

Hence, the value of the optimal investment decision by traditional DCF techniques, i.e., the "NPV rule of thumb", is complemented by the value of the flexibilities and their uncertainties, which is added to the value of the initial optimal decision. In this sense, the ROV can complement the DCF calculation through the valuation of flexibilities and uncertainties. Finally, through this line of reasoning, we can formalize equation (5) below, according to Trigeorgis (Trigeorgis, 1993).

$$VPL_{expanded} = VPL_{tradicional} + Real\ option\ value \tag{1}$$

In the sugar-energy sector, the methodology of economic evaluation by ROV has already been used for some years. In the early 2000s, Brazil’s economics was under a liberal agenda, forcing market players to seek new management practices to stay in the market. In the same period, there was also appreciation of agricultural commodities, with many being traded in the financial market, as well as the beginning of production and the widespread use of renewable fuels worldwide. Thus, new price and demand data were available, so that market uncertainties, that is, uncertainties regarding price movements, supply and demand, as well as regulatory uncertainties, could be modeled by the methodologies already used previously in financial assets.

Regarding the irreversibility of decision-making for the sugar-energy sector, the initial fixed cost of the investment is at least partially irreversible. It is known that physical assets - such as industrial equipment, trucks, tractors, etc. - they devalue over time and can not be fully recovered. In addition, even after such initial investments, decision-making for subsequent periods also involves decisions on irreversible investments, for example in the production of sugar and ethanol, it is not possible to discard the investments to produce them.

In the production of sugar and ethanol in the sugar cane plants, there is an alternative to establish production contracts with cooperatives, which will buy both products at pre-set quantities and prices for the entire harvest. On one hand, such contracts protect the producer from possible low market prices, allowing greater security. Not only, but there is also greater predictability for the entire production chain (Sant’Anna et al., 2015). Therefore, it is noticed that there is an irreversibility in the decision making of investments, which if the decision-maker decides to sell its products to contracts established before the beginning of the harvest, hence it will not be possible to undo such decision entirety. On the other hand, it can not explore the possible flexibilities. Thus, an alternative to the contracts established at the beginning of the harvest would be to the sugar cane plants sell its products in the spot market. In this sense it is possible to explore production flexibilities and price uncertainties.

Regarding the flexibilities of sugar cane plants, according to the literature, ROV theory can model the *option of expand the production*, as there is still excess production capacity (Pederson and Zou, 2009). Such expansion can occur, for example, through the commercialization of the surplus of cogenerated electricity energy. Thus, according to Vollert (Vollert, 2003) and Dias (Dias, 2014), in favorable market situations, there are aggressive ROV that can increase gains. In the literature there are studies that evaluated this option to expand in the sugar-energy sector (De Oliveira et al., 2014; Dias et al., 2011; Samanez et al., 2017; Silva, 2012; Tatoni, 2012). On the other hand, in an equivalent way, it is also possible to carry out an *option to reduce the production*. This is the example of a defensive ROV as it protects the investment in unfavorable market situations.

Another defensive flexibility, which will be researched in this paper is the *switch output option* (Kulatilaka, 1993; Kulatilaka and Trigeorgis, 1994), that is, the choice of the proportion to be produced between ethanol and sugar, also called the conversion option in the Brazilian literature in ROV for the sugar-energy sector. Thus, as there is greater appreciation in the market for one of the products, the sugar cane plants are able to increase the proportion of that one in the production mix (Bastian-pinto et al., 2009; Bastian-Pinto and Brandão, 2007; Dias et al., 2011; Gonçalves et al., 2006; Pantoja et al., 2016; Pessoa, 2011).

More specifically, according to Bastian-Pinto *et al.* (Bastian-pinto et al., 2009), a mathematical model that values the flexibility of production choice between ethanol and sugar incorporates 19% more value than a model that considers a single end product. In this way, the decision maker in a sugar cane plant can choose a new proportion of the production, in order to maximize its revenues and guarantee better financial indicators (Dias et al., 2011).

There are also other flexibilities that can bring value to the assessment in sugar cane plants, which were not found in the literature. They are the *temporary shutdown option* (which is the object of study in this paper) and also the *option of abandonment*. It occurs that, in situations of falls in the prices of ethanol and sugar, the sugar cane plants operate at a loss. Therefore, there is the flexibility to carry out a temporary shutdown in the operation of the plant until prices return to the previous level. In this situation, the plant would not have to incur variable production costs, but only fixed costs. There is also one more alternative, in case of prolongation of the low price period, which is the abandonment option, in which the plants would definitely stop production and would neither incur variable costs nor fixed costs.

In relation to the methodologies used in the sugar-energy sector, they were listed in two groups: (i) methodologies to model flexibilities decision-making; (ii) methodologies to model the sources of uncertainties, that is, the random variables sugar price, ethanol, or even electricity price.

By the literature review, the most used was the binomial (lattice). It happens that, since such methodology requires a simpler mathematical theoretical framework, the greater use of such methodology was already expected. For the use of partial differential equations (PDE), this was found only in the paper of Schmit *et al.* (Schmit et al., 2009). This methodology is convenient for the use of a single uncertainty, or even with a maximum of two uncertainties, if it is possible to keep the homogeneity for the option. As in (Schmit et al., 2009) only one uncertainty was used - in this case, the corn ethanol price -, the ROV approach by PDE is feasible. Yet, in the other papers found, especially in those that worked with an uncertainty for the price of sugar and another one for the one of ethanol, it is not possible to model such projects.

It was also found some studies with Monte Carlo simulation methodology (De Oliveira et al., 2014; Pessoa, 2011). According to Dias (Dias, 2014), for the use of several sources of uncertainty, this is by far the most indicated methodology. Therefore, this methodology is well indicated for such situations.

In order to model the sources of uncertainty, since it is commodity modeling, there is a greater expectation for the use of the mean reversion movement (MRM) for the price variables. Nevertheless, it is also possible to model commodities prices with geometric Brownian motion (MGB), as (Farinelli, 2017; Gonçalves et al., 2006; Zilio and Lima, 2015), for ethanol and sugar prices; (Tatoni, 2012), for electricity prices; and, (Schmit et al., 2009), for the corn ethanol prices, or as in the modeling of other commodities, for instance, oil price as (Postali and Picchetti, 2006).

The preference of using a GBM for modeling the price variables is due to the fact that the modeling of flexibilities becomes easier with this model. As Dias (2014) points out, in the binomial (lattice) methodology and also by PDE, the GBM is easier to apply such methods when compared to the MRM. Moreover, for the use of the methodology by DPE, with GMB is also easier, being possible to arrive at results by analytical solutions, whereas by MRM, the solutions are found by numerical methods more difficultly. Nevertheless, there were studies that chose to use the binomial (lattice) method with MRM, although more difficult, for example, (Dias et al., 2011; Pantoja et al., 2016; Samanez et al., 2017; Silva, 2012). Besides this methodology, for the Monte Carlo simulation, with (De Oliveira et al., 2014; Pessoa, 2011) MRM was also used for the uncertainties.

To conclude this section, a summary is given in Table 1 below, identifying the year of publication of the paper, the author (s), the methods used, the stochastic modeling for the uncertainties, and the evaluated flexibilities.

Table 1 – Summary of the main publications of ROV on sugar-energy sector

Year	Author(s)	ROV Methodology	Stochastic Methodology	Flexibilities
2006	Gonçalves *et al.*	Quadrinomial (lattice)	GBM	Switch ouput option
2009	Bastian-Pinto *et al.*	Binomial (lattice)	MRM	Switch ouput option
2009	Schmit *et al.*	PDE	GBM (corn ethanol)	Entry-exit and mothball options
2011	Pessoa	Monte Carlo simulation	MRM with Poisson jumps	Switch ouput option
2011	Dias *et al.*	Binomial (lattice)	MRM	Expansion option (bioelectricity cogeneration and increase of ethanol and sugar production)
2012	Tatoni	Binomial (lattice)	GBM (power prices)	Expansion option (bioelectricity cogeneration)
2012	Silva	Binomial (lattice)	MRM (power prices)	Expansion option (bioelectricity cogeneration)
2014	Oliveira *et al.*	Monte Carlo Simulation	MRM with jumps (power prices)	Expansion option (bioelectricity cogeneration)
2015	Zilio e Lima	Binomial (lattice)	GBM	Entry option
2016	Pantoja *et al.*	Binomial (lattice)	MRM	Switch ouput option
2017	Farinelli	Binomial (lattice)	GBM	Switch ouput option (crop rotation)
2017	Samanez *et al.*	Quadrinomial (lattice)	MRM	Expansion option (bioelectricity cogeneration)

4. Methodology

4.1. Initial case description

The initial case of this research is a hypothetical sugar-energy plant in Brazil. It is a plant with an attached distillery. Therefore, this unit can produce sugar and ethanol. It is also considered that this unit is already built and with all investment costs already amortized. In short, it is a fictitious plant; but plausible.

It is added that this plant has a partially irreversible decision to close a contract for the sale of its products - ethanol and sugar - with fixed quantities already established in the contract. Therefore, the irreversibility arises from the fact that there are fines if the plant does not comply with the terms of this contract. For this, the plant has previously defined the production mix to be used throughout the harvest, which the plant can no longer change. Otherwise, it will not be able to deliver the pre-established quantity under contract.

On the other hand, there is the alternative of the sugar cane plant to sell in the spot market. Therefore, due to the volatility of prices, the plant acquires flexibility to change the mix in order to produce the most profitable product, or the plant may also temporarily shutdown the production if the margins of the products are not attractive to incur the variable production costs.

Therefore, since there is no reversibility in the decision on the production mix established in a production contract along the harvest, the flexibilities of *switch output option* and *temporarily shutdown option* production add value to the plant. For the alternatives to choose the mix production, it is considered that the plant has the technical capacity to choose to allocate between 40% and 60% of the sugar cane harvested for production between ethanol and sugar. Thus, the percentages used in the simulations are the following percentages between ethanol and sugar: 40% X 60%, 45% X 55%, 50% X 50%, 55% X 45%, 60% X 40%. Hence, there are five possible production alternatives to be evaluated.

According to the Sosnoski and Ribeiro (Sosnoski and Ribeiro, 2012), the uncertainties in the prices of products in the Brazilian sugar and ethanol industry require complex financial and production strategies by the mills, which must have a clear policy regarding the decisions about their production mix. Besides this, Volpe *et al.* (Volpe et al., 2016) conclude that there are opportunities to increase income from changes in the production mix.

With such production mix alternatives, the *switch output option* will be considered, that is, the flexibility to choose the mix that implies a higher profit, i.e., the quantity to be produced of ethanol and sugar that will maximize the firm's profit between the five alternatives described. This is due to the fact that each month the plant can change the production mix and prioritize the product with the highest market price. Plus, there are no production switching costs. Thus, we say that at each operational period (month), an operational decision expires and the firm exercises the option of greater profit between choosing the production mix between ethanol and sugar and shutting down the plant. In the terminology of ROV, this is the forward simulation of European options.

Moreover, the *option of temporary shutdown* is added, which is characterized by the alternative of producing neither ethanol nor sugar in a certain period (month). This stems from low market prices to the point where sales revenue is less than variable production costs. Therefore, the firm prefers to incur fixed costs and not produce. For this situation there will be no cost of reactivation. In addition, it will also be analyzed the flexibility of both options to act together, that is, in a given month, the plant may exercise the switch output option and if it still does not make a profit, it may be exercising the temporary shutdown option. Therefore, it is the *switch output and temporary shutdown option*.

It is added that the operation of the plant will be evaluated over a 54-month horizon, which is equivalent to four and a half years. This value was chosen value on the fact that the sugar cane plantations last on average between three and six harvests (Santiago and Rossetto, 2018). After this period, new costs would have to be incurred to continue production, which will not be included in this study. Therefore, it was considered a period to work on a sugar cane field before its renewal.

For the calculations of the functions of revenue and profit, the following parameters are firstly measured.

m_x: production mix between ethanol and sugar, such that m_x indicates the percentage of the crop used to produce ethanol. In this work, the possible percentages are considered: 40%, 45%, 50%, 55% and 60%, such that x assumes the same percentage values. Similarly, the percentage of the sugar mix is $1 - m_x$.

Q: quantity of sugar cane harvested for each month. In this work it is considered the fixed quantity of 175,000 tons of sugar cane for this parameter. The choice of this parameter was that in Brazil there are currently 307 plants authorized to produce ethanol (Agência Nacional do Petróleo Gás Natural e Biocombustíveis, 2019b) and in the 2017/2018 harvest 641 million tons of sugar cane crops were harvested. Thus, on average, each plant harvested near the average of 175,000 tons of sugar cane crops per month.

C_e: conversion factor in liters/ton for ethanol production. In this paper, it is considered that for each ton of sugar cane it is possible to produce 40 liters of ethanol. In some studies, such as in Albarelli (Albarelli, 2013) and Junqueira (Junqueira, 2015), by means of a technical analysis of production, the authors reached values of 43.4 l/t and 41 l/t, respectively, which, according to the authors, were slightly higher than expected. Therefore, considering a value close to that ones found in the literature, the value of 40 liters of ethanol per ton of sugar cane.

C_a: conversion factor in bags/ton for sugar production. In the literature, Albarelli (Albarelli, 2013) found the value of 130 kg/t, which corresponds to 2.6 bags of sugar. According to the author, in other studies, values between 140 kg/t and 145 kg/t were found. Still, in other studies, such as Cavalett *et al.* (Oliveira et al., 2015) and Mendes *et al.* (Mendes et al., 2017), the values found were close to 50 kg/t. It is noticed that the differences in the amount of production found in the literature are mainly due to the technical aspects of sugar and ethanol production, which will not be detailed here, since it is not the focus of present research. Finally, the value of two bags (100 kg), which was indicated by professionals of the sector. Plus, this value is close to the average of the values found in the literature will be used.

$Trib$: percentage of taxation to be levied on the profit. In the sugar cane plants, the tax burden is related to Corporate Income Tax and the Contribution on Net and Social Profit, such that both taxes total 34% of the profits (Junqueira, 2015; Milanez et al., 2015).

PCT: production cost per ton of sugar cane. According to Fernandes (Fernandes, 2017), the amount of R$ 91.17 will be used.

FC: monthly fixed cost of operation. It is considered that the plant has a fixed monthly cost of R$ 2,000,000.00. According to Pantoja et al.(Pantoja et al., 2016), the fixed costs in sugar cane plants correspond on average to 10% of its gross revenue. In this way, since the revenue calculated in this work was around R$ 20 million, 10% of this amount was used for monthly fixed cost expenses.

TC: total cost of operation, calculated by $TC = PCT(Q) + FC$.

Besides the price series E_t e S_t, which represent, respectively, the stochastic processes of the price of ethanol and sugar, which will be described in more detail in the next section of this paper. In this way, both processes are simulated along the months t.

With these parameters, finally, the revenue and the profit are calculated in each month according to the equations below.

$$R_x = m_x Q C_e E_t + (1 - m_x) Q C_a S_t \quad (2)$$

$$\pi_x = (R_x - TC)(1 - Trib) \quad (3)$$

So, through equations (2) and (3) it is calculated, respectively, the revenue and the profit, such that x indicates the percentage that was allocated to ethanol production from the production mix. Therefore, it is calculated. R_{40}, R_{45}, R_{50}, R_{55}, R_{60}, as well as π_{40}, $\pi_{45}, \pi_{50}, \pi_{55}, \pi_{60}$.

Once this is done, the following production flexibilities are considered. Firstly, there is a *switch output option*. The sugar cane plant analyzed in this paper, it can allocate part of the production to ethanol and the rest to the sugar, thus forming the production mix, as already explained previously. Thus, one has the option $F(t)$, in equation (4), which indicates the production that implies in the greater profit between the different alternatives of allocation of production monthly.

$$F(t) = Max[\pi_{40}, \pi_{45}, \pi_{50}, \pi_{55}, \pi_{60}] \quad (4)$$

Secondly, there is the *temporary shutdown option*. In this option, if the plant does not have a profit with the mix to produce 60% ethanol and 40% sugar, the plant can stop production. However, 30% of the fixed costs to be charged as independent production expenses will still be considered. Thus, we have the option $G(t)$ in equation (5).

$$G(t) = Max[L_{60}, (-0{,}30)FC] \quad (5)$$

The reason for existing expenses even with the plant shutdowned stems from the fact that, although production does not occur, other activities occur. For instance, in a moment of shutdown are made preventive maintenance, such as, cleanings in the equipment (Mendrone and Sousa, 2012). In addition, there are non-operating expenses, such as leases, salaries, harnessing of sugar cane productions by-products, such as vinasse (Watanabe, 2001). According to a case study from Esberard *et al.* (Esberard et al., 2009), the expenses that occur independently of the production of the plant represent the value of 25% of all the total expenditure. However, for the authors, this value was considered low. Thus, it was considered the factor of 30% of all expenditure when the plant is not in production. In addition, other values are also tested in the sensitivity analysis.

Thirdly, there is the *switch output and temporary shutdown option*. In this option, complementing the already calculated switch output option with $F(t)$, if the sugar cane plant still does not have a profit even with this flexibility, it is considered that the alternative of the plant does not produce neither ethanol nor sugar, without incurring variable costs of production, but assuming only partial of the fixed cost. Thus, there is the option $G(t)$ in equation (6), which considers the maximum between $F(t)$ and 30% of the negative fixed cost.

$$H(t) = Max[F(t), -(0{,}30)FC] \tag{6}$$

4.2. Price series modelling

In this paper, the monthly series of hydrated ethanol, in R$/l, and vehicular gasoline (type C, common), in R$/l, are modeled (Agência Nacional do Petróleo Gás Natural e Biocombustíveis, 2019a) and the VHP (Very High Polarized) sugar bag, in R$/bag (Centro de estudos avançados em economia, 2019). The first two from July 2001 to December 2017, while the last from May 2002 until December 2017 as well. All series were restated by the Price Consumer Index, considering December/2017 as the base value.

The fuel price series provided by the ANP consist of a calculation of the average price between fuel stations throughout Brazil. For this, according to ANP (Agência Nacional do Petróleo Gás Natural e Biocombustíveis, 2019a), prices are searched in more than 15,000 gas stations. Although there were price differences among the states, in December/2017, for instance, the coefficient of variation in this month was 6.2% and 11.9% for gasoline and ethanol, respectively (Agência Nacional do Petróleo Gás Natural e Biocombustíveis, 2019a). Therefore, it is noticed that the dispersion is low, mainly for gasoline. Moreover, once it is considerous a fictitious plant, which could be located in the Southeast, or in the Midwest, or even in the Northeast, was considered, a series of prices was considered that regard Brazilian territory as a whole.

For the series of sugar prices, there are several series of prices, for instance, price of crystal sugar, refined, white, among others types of sugar. Nevertheless, it is important to note that most Brazilian sugar production is destined to the foreign market. In the 2017/2018 harvest, in a production of 38.5 million tons of sugar, the export was 27.8 million tons (União da Indústria da Cana-de-Açúcar, 2019). Thus, in this harvest, 72.2% of all sugar produced was exported. Therefore, it was decided to use a series of prices for the external market, the VHP sugar price (Centro de estudos avançados em economia, 2019). Thus, the sugar price series was chosen because it is produced to be sold on the international market. In Figure 4 below it is possible to visualize the behavior of such series, in real prices.

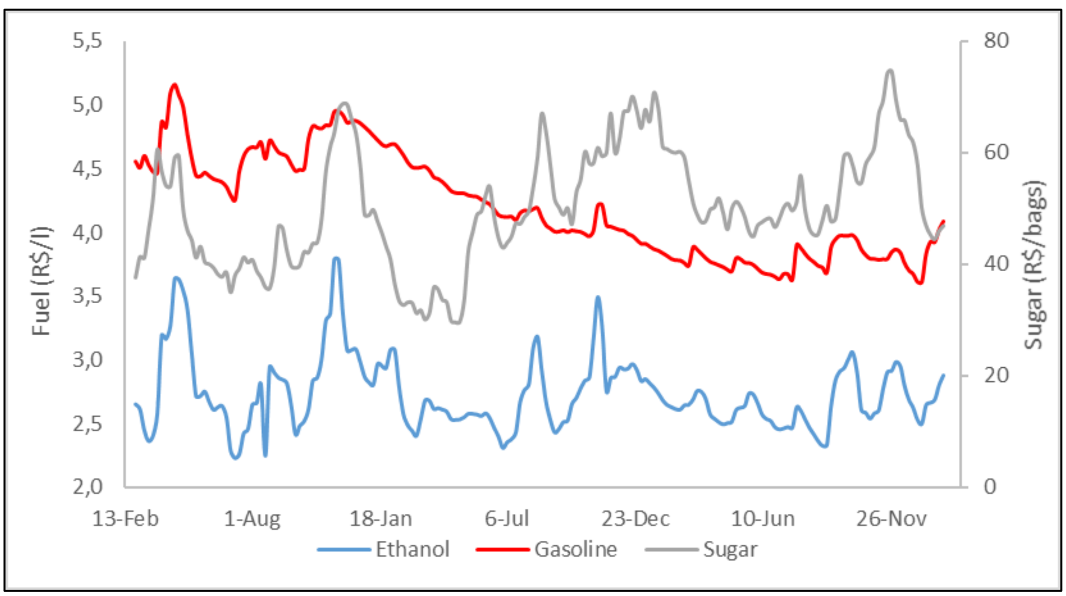

Figure 4 – Ethanol, gasoline and sugar time series

Source: Author’s elaboration with data from ANP (Agência Nacional do Petróleo Gás Natural e Biocombustíveis, 2019a) and CEPEA-Esalq (Centro de estudos avançados em economia, 2019).

Last, for modeling these times series, it will be considered the logarithmic returns of the series. Thus, for each observation of a series P_t, it was calculated $\log\left(\frac{P_t}{P_{t-1}}\right)$.

In the sequence, it will be verified if the ethanol and sugar price series follow a geometric Brownian motion (GBM) or a mean reverting movement (MRM). Thus, the equation (7) defines the GBM.

$$\frac{dX_t}{X_t} = \alpha dt + \sigma dz_t \tag{7}$$

Although the GBM is easier to use for modeling real options with commodities prices, MRM is considered more appropriate, mainly because of its movement follow the laws of supply and demand, such as commodities in general. Thus, for the price series modeling by MRM, the simple Ornstein-Uhlenbeck (O-U) process of one factor, given by equation (8) below.

$$dX_t = \eta(\bar{X} - X_t)dt + \sigma dz_t \tag{8}$$

First, to test the hypothesis that a price series is modeled by an GBM or an MRM, the unit root test is used. For this it was chosen the Ng-Perron unit root test (Ng and Perron, 2001; Perron and Ng, 1996). In Table 2 it is possible to see the results of the Ng-Perron test.

Table 2 – Results of the Ng-Perron test

Price Series	*Deterministics variables*	*Lags*	*Statistics*			
			MZa	*MZt*	*MSB*	*MPT*
Ethanol	Trend and intercept	1	-39,884**	-4,4580**	0,1117**	2,3261**
Sugar	Trend and intercept	1	-22,069*	-3,2852*	0,1488*	4,3547*

Values with ** indicate rejection of the null hypothesis (presence of unit root) at 1%;
Values with * indicate rejection of the null hypothesis (presence of unit root) at 5%.

The results indicated that the null hypothesis, that is, the price series has a unit root, was rejected at the level of 1% for ethanol and 5% for sugar. Therefore, it is concluded that the sugar and ethanol price series are stationary type and will be modeled by an MRM. Then, since discrete data will be used, it is convenient to work with the discrete O-U process. For this, we use the autoregressive model of order 1, AR (1), which is given by equation (9) below.

$$X_t - X_{t-1} = X_{t-1}(e^{-\eta\Delta t} - 1) + \bar{X}(1 - e^{-\eta\Delta t}) + \sigma\sqrt{\frac{(1-e^{-2\eta\Delta t})}{2\eta}}N(0,1) \tag{9}$$

In addition, with the logarithm of the price series, it is possible estimate the parameters a and b of the linear regression in equation (10) below:

$$\log\left(\frac{P_t}{P_{t-1}}\right) = a + (b-1)\log P_{t-1} + \varepsilon_t \tag{10}$$

In this case, for estimating the parameters in MRM, according to equation (10) the values of a and $b-1$ are estimated by ordinary least squares. Thus, with equations (9) and (10) in comparison, one can establish the following equations:

As $b - 1 = e^{-\eta\Delta t} - 1$, since $\Delta t = 1$, therefore $-\ln b = \eta$. Thus, the estimation of the parameter η is given by equation (11) below:

$$\eta = -\mathrm{N}\ln b \tag{11}$$

Since the parameters in the MRM are for annual basis, then N represents the amount of data in a year. In this paper, since the time series used are all monthly, then $N = 12$.

Moreover, as $a = \bar{X}(1 - e^{-\eta\Delta t})$ and $\eta = -\ln b$, so it is possible to estimate the parameter σ in the model O-U through equation (12) below:

$$\sigma = \sigma_{\varepsilon}^{2} \sqrt{N} \sqrt{\frac{2 \ln b}{b^2 - 1}} \tag{12}$$

Last, the parameter $\bar{X}$ – MRM equilibrium price – is estimated by comparing equations (9) and (10), such as by calculating the expected value of equation (9), one obtains $E(\ln P_t) = \mu = a + b\mu$. As a result, $\mu = \frac{a}{1-b}$. Ergo, once $\bar{X}$ is estimated according to the following equation (13).

$$\bar{X} = \mu = \frac{a}{1-b} \tag{13}$$

Hence, with he parameters η, σ and $\bar{X}$ of MRM it is possible to model the price series, as they are stimated by equations (11), (12) and (13) respectively, for each price series. The results are shown in Table 3 below.

Table 3 – Results of MRM parameter estimatives

Parameters	*Ethanol*	*Sugar*
σ	19,361%	23,028%
η	1,820	0,621
$\bar{X}$	1,002	3,916

In addition to the values estimated in Table 3 above, it is also necessary to define the initial price P_0, for this value will be used the last of the historical series, that is, the value found for December 2017; X_0, initial price in logarithms; risk-free rate, quantified using the long-term interest rate (BNDES, 2018); and, the risk premium to be subtracted, estimated by capital assets price model (CAPM). All of these values follow below in Table 4.

Table 4 – Input values for the simulations

Parameters	*Ethanol*	*Sugar*
P_0	2,879	46,830
X_0	1,057	3,847
r	0,528%	
π	0 (zero)	

With all the estimated parameters and initial values defined, the Monte Carlo simulation is applied.

4.3. Real options valuation modeling by Monte Carlo simulation

In this paper, the Monte Carlo simulation (MCS) will be used to generate future cash flows from the production and sale of ethanol and sugar. Thus, for each interval Δt a new price value is simulated, that is, samplings of the random variables are done computationally with a number of 100,000 simulations (samplings).

So, it is possible to visualize the output variable, in this case, the NPV. As a result, this variable has a probability distribution and it is possible to calculate all summary measures. Therefore, it is possible to evaluate the NPV in such a way that it is possible to calculate its mean, standard deviation, percentiles and, more important, to evaluate the probability of obtaining positive NPV, that is, $P[NPV > 0]$.

In equation (14) below we have the simple risk neutral model of O-U, indicated by the superscript Q to differentiate from the real model.

$$dX_t^{\,Q} = \eta \left(\bar{X} - \frac{\pi}{\eta} - X_t \right) dt + \sigma dz_t^{\,Q} \tag{14}$$

After this step, in order to perform the simulations, it is necessary to use a discretized version of the equation (14) above. Then, we have the equation (15) below.

$$X_t = X_{t-1}(e^{-\eta\Delta t}) + \left(\bar{X} - \frac{\pi}{\eta}\right)(1 - e^{-\eta\Delta t}) + \sigma\sqrt{\frac{(1-e^{-2\eta\Delta t})}{2\eta}}N(0,1) \tag{15}$$

In equation (15), the calculation of X_t is done by the sum of the expected value with its random term multiplied by the standardized normal distribution, i.e., $N(0,1)$. However, X_t indicates the logarithm of prices. Thus, to obtain the simulation of the price series P_t, it is used the equation (16) below.

$$P_t = exp\left(X_t - (1 - e^{-2\eta t})\frac{\sigma^2}{2\eta}\right) \tag{16}$$

Finally, one should consider whether stochastic processes are correlated. Since sugar and ethanol are products of the same input, that is, sugarcane, there is an expectation of correlation between their stochastic processes. Then, according to Mun (Johnathan. Mun, 2006) when critical decision-making factors are correlated, it is convenient to simulate a correlation factor so that modeling becomes closer to reality. For this, following the procedure proposed by Dias (Dias, 2004), are the normal random variables X, Y and W with correlation ρ between X and Y, then by means of two independent samplings ε_X and ε_W, which follows a normal standardized distribution, it is possible to use the Cholesky formula, given in the following equation (17) to obtain a sampling for the variable Y, such as in this equation 44.62% was used for the correction ρ.

$$\varepsilon_Y = \rho^2\, \varepsilon_X + \varepsilon_W\, \sqrt{1-\rho^2} \tag{17}$$

5. Results

First, it was considered as irreversible decision-making within an environment of a sugar cane plant, the sale of its products, that is, sugar and ethanol, in contracts established before the beginning of the harvest. In addition, during the 2018/2019 harvest, the percentage of the harvest allocated to ethanol production was higher than 60% (União da Industria de Cana de Açúcar - UNICA, 2018). Thus, it was analyzed the case of the plant producing 60% of ethanol and 40% of sugar as irreversible decision, so that the production is sold at market prices.

Since MCS is applied to price uncertainties, it is possible to obtain a probability distribution. The results shows a NPV distribution with mean and standard deviation of R$ 13.489 million and R$ 36.603 million, respectively. Moreover, the probability of deliver a positive NPV is 62.92%. In Figure 5 below it is possible to visualize the probability distribution of the NPV.

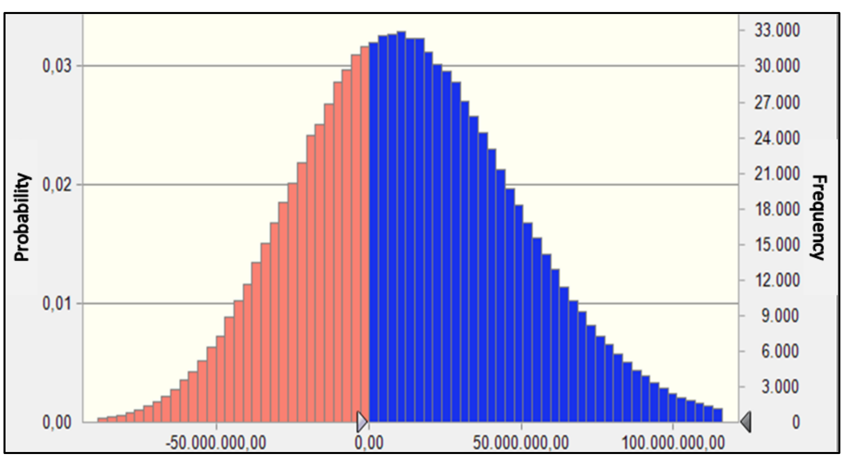

Figure 5 – Initial case probability distribution

In Figure 5 it is possible to visualize the probability distribution of the NPV for the *initial case*, that is, the irreversible decision to sell the production in contract. In blue there is an area corresponding to positive NPV, while in red, the NPV is negative. It is also noticed that even with the maximization of ethanol production, it is possible to obtain negative NPV. After all, for allocation of 60% of the mix for ethanol production, it implies $P[NPV > 0] = 62.7\%$, that is, as market uncertainties vary, there is a 37.3% chance of obtaining NPV negative.

For the *temporary shutdown option*, the results indicate that the *temporary shutdown option* increases the expected NPV value of the initial case analyzed by 62.50%, to R$ 21,954 million. Not only, but the probability of NPV being positive increases from 62.7% to 74.39%. Thus, there was an increase of R$ 8,443 million with this option value. Finally, in the evaluated model, in the horizon of 54 months analyzed, for 100,000 simulations, in 92% of cases there was the case of at least one temporary stop option being exercised.

In addition, there is the *switch output option*. The results indicated that, compared to the initial case, there is an appreciation of 25.1% of the expected NPV value to R$ 16.71 million, with $P[NPV > 0] = 64.26\%$. Therefore, the value of this option adds R$ 3,356 million to the initial case. Although the returns are favorable for the allocation of 60% for ethanol, in the horizon of 54 months of production, there were moments that this mix was not the optimal one. According to the model, for 100,000 simulations, in 82.2% there was at least one month of production that the 60% ethanol mix was not optimal.

It is also possible to analyze the effect of the joint interaction between the *switch output and temporary shutdown option*. The results indicated for the interactions between these options, NPV with expected value and standard deviation of R$ 25,124 million and R$ 32,864 million, respectively, with $P[NPV > 0] = 75.58\%$. In Figure 6 below it is possible to visualize the probability distribution of the interaction between these conversion and temporary shutdown option.

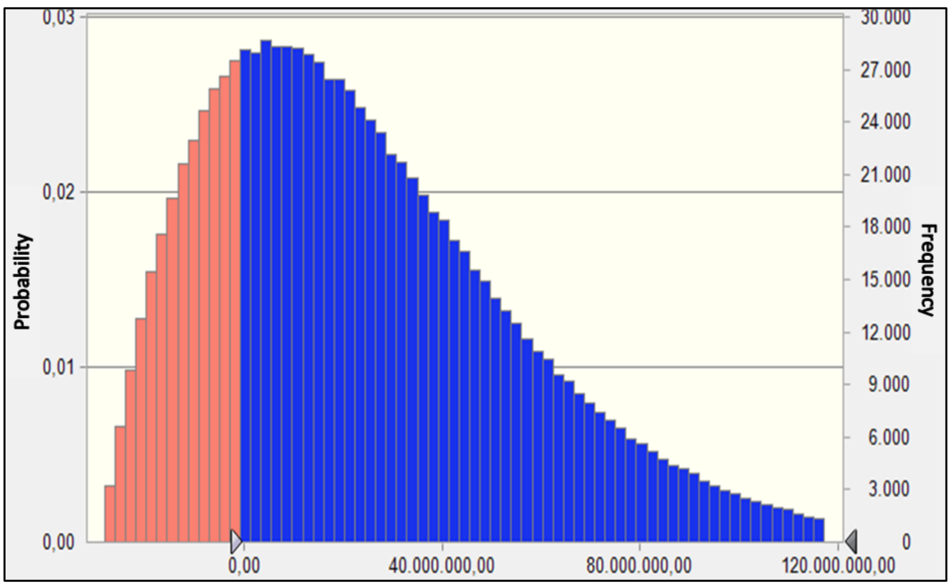

Figure 6 – Switch output and temporary shutdown option probability distribution

In Figure 6, in red there is the mass of the negative distribution and, in blue, the positive one. It is noticed that the positive mass is much larger, indicating a remarkable asymmetry in the distribution. This is due to the fact that the switch output and shutdown options limit the losses that would occur without them.

In this sense, the option value becomes R$ 11,770 millions, which is equivalent to an increase of 88.14%. Thus, the *switch output and temporary shutdown option* together can increase the value of the plant, avoiding the undesirable effects of the market uncertainties. It is possible to compare the probability distributions before and after the OR, as shown in Figure 7 below.

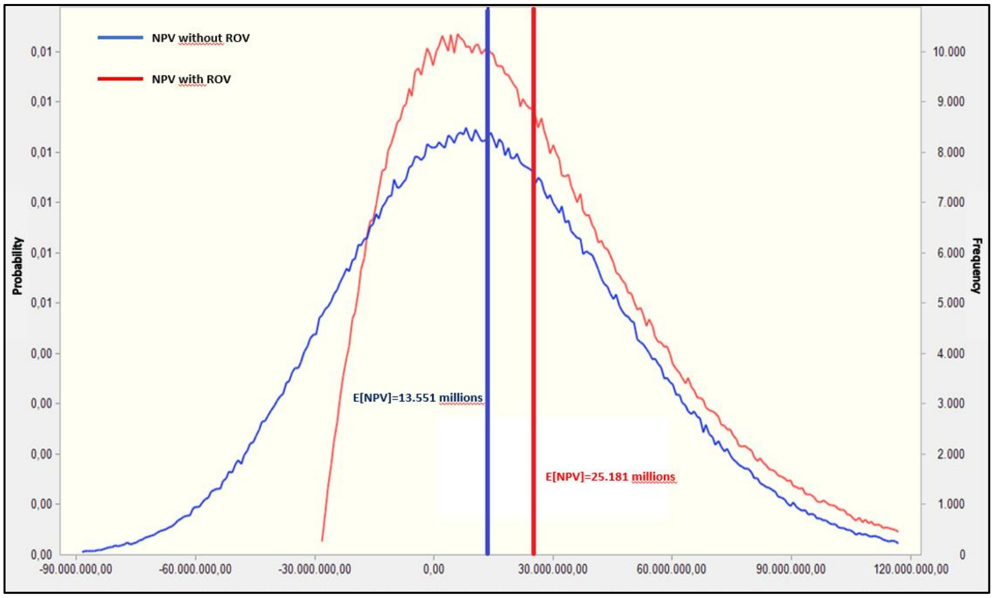

Figure 7 – Probability distributions with and without flexibilities

The Figure 7 shows the distribution of the NPV of the plant, considering the *initial case*, with mix of 60% ethanol and 40% sugar in blue, and the NPV of the plant with the *switch output and temporary shutdown* option in red. On the left side of the picture, the NPV of the plant (in blue) assumes lower values, reaching -R$ 90,000,000.00, while the NPV of the plant with real options (in red) starts from -R$ 30,000,000.00. This difference indicates the main advantage of applying the real options of switch output and temporary shutdown in sugar cane plants, that is, the limitation of losses. In addition, this figure also shows by vertical lines the expected value of each distribution, such that the difference between them, that is, the value of R$ 11.770 million indicates the gain from the flexibilities.

Thus, the result is that for the value of a sugar cane plant, the swith output and temporary shutdown options are additive. Moreover, they are *purely additive* type. This stems from the results of the interaction between the flexibilities. These real options when calculated separately before and summed later results in the same value when calculated together. Therefore, one option did not affect the other.

Finally, to summarize the results, it follows Table 5 with the results of the expected NPV values of each option, as well as for the initial case.

Table 5 – ROV results's summary

	Expected value of NPV[1]	$P[NPV > 0]$	*Percent increase regarding the initial case*
Sugar cane plant (initial case)	13,510	62,92%	-
Sugar cane plant with switch output option	16,710	64,26%	25,13%
Sugar cane plant with temporary shutdown option	21,953	74,39%	62,50%
Sugar cane plant with switch output and temporary shutdown option	25,124	75,58%	88,14%

[1] In millions of reais (R$).

5.1. Sensitivity analysis

In this section, it will be made a sensitivity analysis in the input parameters of the initial case and also in the chosen flexibilities.

Fixed cost: For the parameter fixed cost, its initial value was set at R$ 2,000,000.00. So, positive and negative changes were made at 10%. Comparing to the initial case, these changes imply 48% negative and positive variations in the expected NPV value. Considering the switch output option, the NPV expected value had changes of 37%, for the temporary shutdown option, 24% and, finally, for the switch output and temporary shutdown option, 21%. Thus, for the options that add more value, the fixed cost influences less on the model.

Production cost per tonne of sugar cane: R$ 91.17 was used and 10% positive and negative changes were made, which led to new changes of more than 360% in the expected value of the NPV for the initial case; 276% for the switch output option; 184% for temporary shutdown option; and, 163%, for the switch output and temporary shutdown option.

It is also worth mentioning that increasing the production cost per tonne of sugar cane by 10%, the probability of NPV being positive decreases to low values, reaching 16.51% for the initial case and even for the switch output and temporary shutdown option, up to 32%. On the other hand, a 10% reduction implies probabilities greater than 95% if a positive NPV is obtained. Hence, it can be seen that, by the model, the production cost per tonne of sugar cane is a very relevant parameter for the success of the plants.

Production Conversion Factors: For conversion factors, it was initially considered that from one tonne of sugar cane, it can produce 40 liters of ethanol and two bags (100 kg) of sugar. Again, positive and negative changes were also made in 10% in these parameters. The results indicated that such changes in the conversion of ethanol imply greater percentage changes in the expected value of the NPV, as for the initial case and as for the analyzed options, when compared with the changes in the sugar conversion. Only with the switch output and temporary shutdown option that the NPV remains positive for the whole analysis of the sensitivity of the conversion factors.

Taxation: Regarding the sensitivity analysis in taxation, the positive and negative changes in 10% imply low changes in the expected NPV value. Not only, but the probability of the NPV being positive little was changed too. It can be seen that, thus, the parameter of taxation was the one that influences the less the NPV of the plants.

Correlation: Correlation changes were tested for the simulation of price series. For the initial case was calculated the value of 44.62% with historical data. Now, for the sensitivity analysis, the values of -100%, -50%, 0%, 50% and 100% were tested. The results of this analysis indicated that the expected NPV value, for the initial case mainly, did not show significant changes. On the other hand, the standard deviation of NPV has changed significantly. For negative correlations, the percentage change of the standard deviation was negative, for example, with a correlation of -100%, the standard deviation was reduced by 70%, whereas for positive correlations, there was an increase in the standard deviation. Moreover, the probability of the expected value of NPV to be positive was higher when the correlation was negative. In simulations with a -100% coefficient, the probability was greater than 95%.

Ergo, it is perceived that a positive correlation implies both gains and losses. However, negative correlations imply lower profit and loss amounts. Finally, there is greater protection for the uncertainty environment in the sugar cane plants when ethanol and sugar prices have negative correlations.

6. Conclusions

This paper proposed to carry out a study on decision making in sugar cane plants using the real options valuation (ROV) methodology. With this proposal, it was verified how ROV can bring better economic results, through the quantification of the defensive managerial flexibilities in an environment formed by uncertainties, by which, the performance of the plants can vary, to the point that the NPV of the production of sugar and ethanol in the plant is no longer positive. In this sense, with flexibilities well exploited, they can act as a hedge instrument, valuing these ventures.

The managerial flexibilities evaluated were (1) the *switch output option*, which allows to change the production mix, that is, the percentages of ethanol and sugar that will be produced; (2) the *temporary shutdown option*, once in adverse market price situations, the plant can stop production, reducing its costs; and, (3) the *switch output and temporary shutdown option* together. These options were analyzed in comparison to the partially irreversible decision of a sugar cane plant to allocate 60% of the sugar cane harvested for the ethanol production and the remaining 40% for the sugar production, which is established in contract, not allowing any change, therefore, an irreversible decision.

In light of the regulatory economic context of the sugar cane sector in the last decade - in which several plants were closed and others were subject to judicial reorganization - the results showed that the flexibilities listed in the previous paragraph can increase the expected value of a sugar cane plant by up to 88%, when considered the switch output and temporary shutdown option; 62.5%, temporary shutdown option; and, 25.13%, switch output option. In this sense, since such flexibilities are defensive, they can deliver better economic results in such an uncertain market environment. Moreover, while in the initial case the probability of the present value of the plant being positive was 62.9%, with these flexibilities, this value can increase up to 76%, reducing the risk in the sugar cane plants.

Not only that, by the analysis of the sensitivity of the parameters in the evaluation of the plants, the result is that the lower the correlation between the stochastic processes of sugar and ethanol, the lower the risk for the plant. In such a way that for a correlation of -100%, the probability of the expected value of NPV to be positive of the plant is higher than 93%. Thus, the greater the opposition between the formation of prices between ethanol and sugar, the greater the chances are that the plant will avoid a crisis like the one that occurred in the beginning of the year 2010.

Finally, it is expected that the results found and conclusions drawn in this paper can help managers and also public policy makers in the sugar-energy sector.

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