Quantitative Analysis of the Economic Risk of Sugarcane Cultivation for Bioethanol Production: A Case Study in Brazil

Danilo Simões,* Ricardo Ghantous Cervi, and Gislaine Cristina Batistela

The management of variables with uncertainties in stochastic cash flow models related to capital investments in energy crops projects allows, in addition to risk measurement, the adoption of proactive measures that can assure the generation of value to the project. This study analyzes the economic feasibility of sugarcane cultivation for bioethanol production from sugar cane molasses, under technical and economic uncertainty. The analysis characterizes sugarcane productivity, capital investment, production costs, and costs of cutting, loading, and transport, considered as stochastic variables. For this, the uncertainty was propagated through Latin hypercube sampling. Sensitivity analysis was also performed to assess the impact of these variables. The results indicated that the productivity of the crop and the sugarcane price in the conveyor belt are determinant to guarantee the economic value of the investment project. There is a high probability of achieving positive NPV (net present value), in addition, MIRR (modified internal rate of return) is 5% higher than MARR (minimum acceptable rate of return).

Keywords: Uncertainty; Renewable energy; NPV; Cost estimate; Stochastic analysis

*Contact information: São Paulo State University (Unesp), Campus of Itapeva – Rua Geraldo Alckmin, 519, Itapeva, SP 18409-010, Brazil; *Corresponding author: danilo.simoes@unesp.br*

INTRODUCTION

Sugarcane is the main crop and one of the best sources of renewable energy in Brazil (Signor *et al.* 2014). Among the large crops, it stands out as the plant with the greatest potential for the production of dry mass and energy per unit area in a single cut per year (Silva *et al.* 2014). The sugarcane bagasse is traditionally used to generate the steam needed in sugar mills and in ethanol distillation (Bizzo *et al.* 2014). As a renewable substitute for petroleum fuels, it has attracted increasing attention due to economic, environmental, and energy security considerations (Li and Hu 2016).

Under the economic prism, the basic premise is the exact knowledge of the amounts spent on sugarcane cultivation for bioethanol production from sugar cane molasses, which aims to express profitability, as well as to accurately measure the degree of risk of capital investments.

The main factors that determine farming system profitability include labor costs, price premiums for product quality, and input costs (Ponisio and Ehrlich 2016). These are either considered cumulatively, *i.e.*, over the entire lifetime of the plantation, or converted to annuities and are expressed per unit land area costs (El Kasmioui and Ceulemans 2012).

The costs calculations are more and more plagued by assumptions, and many questions arise during estimates. Therefore, one possibility is the application of quantitative estimates for risk assessment, an approach that has become common practice in many disciplines (Alexander and Sarabia 2012; Schwabe *et al.* 2015). Thus, to quantify the propagation of cost uncertainty, a stochastic simulation technique can be applied.

A widely used example is Latin hypercube sampling (Rajabi *et al.* 2015). Latin hypercube sampling (LHS) is generalized in terms of a spectrum of stratified sampling (SS) designs referred to as partially stratified sample (PSS) designs (Shields and Zhang 2016). In this way, uncertainty can be quantified by the risk of the investment project.

Risk is defined by the probability for an event of negative impact to occur and the extent of the resulting consequence, once this event has taken place (Sultania *et al.* 2016). Assessing, comparing, and evaluating risks are fundamentally moral tasks and are crucial for financial stability (Shrader-Frechette 1986; Zhang *et al.* 2017), especially when it comes to capital investments for sugarcane cultivation for bioethanol production from sugar cane molasses, because the profitability of the crop is vulnerable to the quality of the raw material and the prices paid to the rural producers.

In this perspective, a stochastic model was constructed from the technical-economic coefficients of sugarcane cultivation for bioethanol production from sugar cane molasses under uncertainty conditions, to analyze and quantify the economic risks involved by means of Latin hypercube sampling.

EXPERIMENTAL

Case Study

The sugarcane cultivation in an area of a bioethanol producing plant was considered to analyze the economic feasibility. The study area is located in the Midwest region of São Paulo State, belonging to the Rural Development Office of Botucatu - SP.

According to the Brazilian Soil Classification System, the soil type of the region presents the soil units Dystrophic Red Latosol (DRL) and Lithic Neosol (RL) (Santos *et al.* 2013). In consonance with Wilhelm Köeppen classification, this area belongs to the Cw climate, corresponding to the Wet Mesothermal climate, with small water deficiency (B2rB’4a') as stated in Thornthwaite specification.

Formation of Sugarcane Field

The management, used after the sugarcane reforestation, considered that one cycle of the sugarcane crop allowed the exploration of five cutting stages. The analyzed production system was characterized as a mechanized one.

The soil was prepared by harrowing with the use of an agricultural tractor with engine power at a nominal rotation speed of 132 kW (180 hp), engaged mechanical front wheel drive (MFWD), and with deep plowing grid, four-plow rods, and a leveling harrow.

The distribution of dolomitic limestone and agricultural gypsum was carried out with a distributor drawn by an agricultural tractor with engine power at a nominal rotation speed of 95.6 kW (130 hp) and engaged MFWD.

The terraces were prepared with a 16-disc trawler, carried out by an agricultural tractor with engine power at a nominal rotation speed of 132 kW (180 hp) and engaged MFWD.

For the application of agricultural pesticides, an agricultural tractor was used with engine power at a nominal rotation speed of 77.2 kW (106 hp), engaged MFWD, and a sprayer with the capacity for 600 liters with a 14-meter spray bar.

The used planter, in addition to the purposeful activity, developed the grooving operations, fertilization, distribution of sugarcane billets, and furrow covering, simultaneously, in two planting lines, driven by an agricultural tractor with engine power at a nominal rotation speed of 132 kW (180 hp) and engaged MFWD.

The sugarcane variety considered was the genetically improved RB86-7515, from the seedling nursery of the plant under study. Planting spacing was 1.5 m between rows with a density of 18 buds per meter, cultivated under a rainfed system.

Production Costs

For the estimation of the variable costs, the cost components that were modified proportionally according to the level of the operations required for the production were considered. Therefore, with expenditures for fertilizers and soil correctives, agricultural pesticides, and seedlings, mechanized operations were considered, besides the costs of cutting, loading, and transportation, that is, with inherent expenditures to the conventional techniques used in the crop.

The cost of remuneration of the land factor, the cost of exhaustion of the sugarcane crop, and the estimated cost of administration from the percentage of 5.0% over variable cost were considered as fixed costs. Considering the sum of variable and fixed costs, the production costs (PC_t) were constituted for each cutting stage. As to the total production costs (TP_c), the sugarcane field reform costs (SR_c) for sugarcane field reform and PC_t were weighted.

Monetary values were expressed in US Dollars (USD), and the exchange rate was the price of the official foreign currency from the Central Bank of Brazil (Banco Central do Brasil 2017) at sale price, measured in units and fractions of the national currency, which was 3,1261 BRL on August 7th, 2017.

For the estimation of the remuneration for the use of land factor (USD ha yr.$^{-1}$), the mean value of the top quality land was used for the region under study, during the period of the evaluated harvests (Instituto de Economia Agrícola 2017).

Economic Analysis

The period between the harvests of 2011/2012 and 2015/2016 was considered for the calculation of the revenues. The values were deflated by the General Price Index - Internal Availability (Mendes and Padilha Junior 2007) based on April 2017 values. Revenues (RE_t) were obtained for each cutting stage (t = 1, … ,5) from productivity data (PR_t) provided by the bioethanol plant, and the total reducing sugar (TR_t), raw material quality (RM), and sugarcane price on the conveyor belt (SP_t), according to data from the Brazilian agriculture directory (Agrianual 2016), is expressed in Eq. 1.

$$RE_t = (TR_t PR_t RM) + (PR_t SP_t) \tag{1}$$

In the profitability analysis, sugarcane field reform costs, revenue, and production costs were assumed for each cutting stage. Thus, this analysis was calculated from the discounted cash flow (CF) according to Eq. 2,

$$CF = SR_c + \sum_{t=1}^{5} CF_t, \tag{2}$$

where $CF_t = RE_t - PC_t$, for $t = 1, \ldots, 5$, is the cash flow for each cutting stage.

Generally, the probabilistic profitability analysis is based on the measurement of outputs such as the net present value (NPV), the modified internal rate of return (MIRR) and the profitability index (PI) for a given capital investment, considering the cash flows over the lifetime of the sugarcane crop.

Therefore, a discount rate calculated using the Capital Asset Pricing Model (CAPM) was considered as cost of equity, *i.e.*, the minimum acceptable rate of return (MARR) required for the project, expressed in Eq. 3,

$$K_e = k_{rf} + \beta_e\left(k_m - K_{rf}\right) \quad (3)$$

where K_e is the cost of capital; k_{rf} is the risk-free interest rate; β_e is the systematic risk of agriculture and k_m is the expected return on a market portfolio.

In general, NPV is an indicator of merit of the investment project, reflecting how much the project added to economic value, from the sum of costs and benefits generated over the lifetime of the project, discounted to the opportunity cost of capital (Eq. 4),

$$NPV = \sum_{t=1}^{5} \frac{CF_t}{(1+i)^t} - CC_0 \quad (4)$$

where t is the period in which costs and revenues occur for each cutting stage and i is the interest rate.

When calculating MIRR, a compatible rate is used to reapply the profits generated each year and another convenient rate for raising funds in the event of negative cash flows; in addition, it is mainly recommended for unconventional cash flows to eliminate the problem of multiple rates of return (Eq. 5).

Thus, the historical series of the yields credited to the Total Savings Account between January 2nd, 2006 and July 31st, 2017 were used for MIRR calculation, to project the reinvestment rate and the data referring to the rate of the Special Clearance and Escrow System (SELIC), observed between January 2006 and July 2017, to obtain the inherent rate of fund-raising.

$$MIRR = \left[\frac{\sum_{t=1}^{5} VF_i(1+i)^{5-t}}{\sum_{t=1}^{5}\frac{|VP_d|}{(1+i)^t}}\right]^{\frac{1}{5}} - 1 \quad (5)$$

where VF_i is the future value of inflows (net positive values, in each t period of cash flow), and VP_d is the present value of expenditures (net negative values, in each t period of cash flow).

The PI analysis aims to measure the success and efficiency of the companies in the use of their sources of financing for profit generation, with the purpose of assessing the capacity of the company to profit in a future exercise. Mathematically, the PI is calculated by the present value of the analyzed period, on the initial investment (Eq. 6).

$$PI = \frac{\sum_{t=1}^{5}\frac{CF_t}{(1+i)^t}}{CC_0} \quad (6)$$

Risk Analysis

Risk measurements are useful analytical tools in situations of uncertainty and are often used in economics to account for uncertainties in investment projects (Abadie and Chamorro 2013). Thus, the risk analysis is based on a stochastic process on known information, in which the output values are sampled in a pseudorandom way, in consonance with the respective probability distributions of the model inputs.

Latin hypercube sampling was applied to the model to incorporate stochastic solutions by means of functions that describe the transformations of model inputs into outputs of interest, ensuring the same seed (12345) for the executed model, in order to provide reproducible results. Thus, NPV sampling was performed with k = 1, … n

iterations (n = 100.000), as described in Eq. 7.

$$NPV = f(S_1, \ldots, S_k) \tag{7}$$

where f denotes the function defined by the simulation model, S_k the simulation results in a set of n NPVs; thus, the NPV could now be described by a particular distribution.

The probability density function is used to calculate the NPV probability belonging to an interval [a, b], denoted by $p(NPV)$, according to Eq. 8.

$$\mathrm{P}(a \leq NPV \leq b) = \int_a^b p(NPV)\, dNPV \tag{8}$$

The probability of the NPV being lower than some x value is calculated by means of the cumulative distribution function, *i.e.*, the probability of occurrence of the NPV value being at maximum x expressed according to Eq. 9.

$$\mathrm{P}(NPV \leq x) = \int_{-\infty}^{x} p(NPV)\, dNPV \tag{9}$$

Consequently, probabilistic analysis of the MIRR and PI outputs was performed in a similar way to the procedures used to generate NPV pseudo-random samples.

Table 1. Inputs from the Stochastic Simulation Model for Sugarcane Cultivation for Bioethanol Production in a Region of Brazil

Input	Unit	Parameters		
		Minimum	Most Likely	Maximum
Sugarcane field reform costs	USD ha^{-1}	2,254.40	2,652.24	3,050.07
Production costs - 1st stage	USD ha^{-1}	1,896.91	2,231.66	2,566.41
Production costs – 2nd stage	USD ha^{-1}	1,655.38	1,947.50	2,239.63
Production costs – 3rd stage	USD ha^{-1}	1,343.89	1,581.05	1,818.21
Production costs - 4th stage	USD ha^{-1}	1,285.72	1,512.61	1,739.50
Production costs - 5th stage	USD ha^{-1}	1,182.03	1,390.62	1,599.22
Productivity - 1st stage	t ha^{-1}	110.50	130.00	149.50
Productivity – 2nd stage	t ha^{-1}	93.50	110.00	126.50
Productivity – 3rd stage	t ha^{-1}	81.60	96.00	110.40
Productivity - 4th stage	t ha^{-1}	72.25	85.00	97.75
Productivity - 5th stage	t ha^{-1}	68.00	80.00	92.00
Total reducing sugar - 1st stage	USD kg^{-1}	0.16	0.19	0.21
Total reducing sugar – 2nd stage	USD kg^{-1}	0.17	0.20	0.23
Total reducing sugar – 3rd stage	USD kg^{-1}	0.17	0.20	0.23
Total reducing sugar – 4th stage	USD kg^{-1}	0.16	0.18	0.21
Total reducing sugar – 5th stage	USD kg^{-1}	0.15	0.18	0.20
Sugarcane price in the conveyor belt - 1st stage	USD t^{-1}	24.87	29.25	33.64
Sugarcane price in the conveyor belt – 2nd stage	USD t^{-1}	22.70	26.70	30.71
Sugarcane price in the conveyor belt – 3rd stage	USD t^{-1}	20.31	23.89	27.48
Sugarcane price in the conveyor belt - 4th stage	USD t^{-1}	19.72	23.20	26.68
Sugarcane price in the conveyor belt - 5th stage	USD t^{-1}	22.29	26.22	30.15
Raw material quality	kg t^{-1}	114.79	135.10	155.25

In this work, parameters with uncertainties (inputs) that allowed the quantification of the economic risk of the sugarcane cultivation for bioethanol production are presented in Table 1, with the respective units of measurements and descriptions of the distribution parameters. The used distribution was the symmetric triangular, because it is easy to understand and commonly used in uncertainty analyzes when there is no plausible information about the probability distribution of the variables weighted in the stochastic model (Simões *et al.* 2016). Therefore, a variant of ± 15.0% of deterministic values was delimited, based on the opinion of experts about the influence of each parameter on the economic viability of sugarcane cultivation for bioethanol production from sugar cane molasses.

RESULTS AND DISCUSSION

Technical Results of the Sugarcane Cultivation for Bioethanol Production

The productivity values provided by the bioethanol plant resulted in an average productivity of 100.2 t ha^{-1} with a 20.5% variation. In addition, the highest productivity (130.0 t ha^{-1}) was obtained in the first cutting stage, in which the productivity probability of the first cutting stage was less than 140.3 t ha^{-1} is 95%.

So, the average productivity was higher than the result made available by Agrianual (2016), which resulted in an average productivity of 92.0 t ha^{-1} for the 2016/2017 crop season. It is important to emphasize that productivity is related to diverse edaphoclimatic and management factors (Bastos *et al.* 2016). Therefore, because it is not the subject of this study, the inference about productivity may be dubious.

Total reducing sugar is a payment measure that considers quality parameters of sugarcane. In this payment system, the final price of the raw material depends on the sales prices of the traded products, besides exposing the sugarcane producer to market risks (Burnquist 1999; Sachs 2007). Therefore, this indicator used to pay the producer presented an average of 0.19 USD kg^{-1} and a standard deviation of 0.01 USD kg^{-1}, while the highest value was obtained in the second stage (0.21 USD kg^{-1}).

Raw material quality can be defined as the succession of characteristics that are intrinsic to the plant, altered by agricultural and industrial management, which define the potential for the production of sugar and alcohol (Rhein *et al.* 2016). In this way, the better the yield of total recoverable sugars, the greater the value received by the sugarcane producer. Thus, this variable that is determinant for sugarcane cultivation for bioethanol production from sugar cane molasses, resulted in a mean value of 135.0 kg t^{-1} with a standard deviation of 8.3 kg t^{-1}.

Economic Profitability Analysis

Sugarcane field reform costs have been investigated by multiple studies (Jonker *et al.* 2015), due to the importance that the cultivation cost exerts on the final cost of the product; for instance, costs with the production of sugar, ethanol, and electricity. Nevertheless, the estimated cost of sugarcane cultivation for bioethanol production from sugar cane molasses is weakened due to inclement weather, pests, diseases, soil conditions, among other factors, which impact on the financial investment necessary for the implantation of the crop.

As a result, the average cost of implementing one hectare for sugarcane cultivation for bioethanol production from sugar cane molasses was 2,652.24 USD, with a 90%

confidence interval, ranging from 2,651,40 to 2,653.09 USD. Among the expenditures that had the greatest impact on this cost were agricultural pesticides, which accounted for 33.8% of the total, followed by the cost of land that demanded 20.1% and, consequently, the expenses with fertilizers that demanded 16.0%.

It is important to note that good sugarcane cultivation practices, that is, the use of optimum amounts of fertilizers and agricultural pesticides, as well as reducing environmental impacts, allow the reduction of sugarcane production costs (Prasara-A and Gheewala 2016; Sawaengsak and Gheewala 2017).

Production cost has always been a controversial issue, especially regarding allocation. Since there is no prevailing methodology and the dissemination of techniques and success stories is poor, the subject ends up being restricted to empiricism (Oliveira *et al.* 2015).

Owing to inherent uncertainties to the cost of production, especially the costs of agricultural production due to the susceptible conditions that are inserted, the average cost of production per hectare was 1,732.69 USD, considering the five cutting stages of sugarcane, that is, sugarcane from the first cutting stage called the "cane plant"; from the second stage of cutting known as "soca"; and from the third to the fifth stage, as "ressoca" termed by Dalri and Cruz (2008).

The total production cost (TP_c) resulted in a mean value of 11,315.68 USD ha^{-1}, with 5% of the simulated TP_c values lower than 10,833.55 USD ha^{-1}. The sugarcane field reform costs (SR_c) presented the highest positive Spearman rank-order coefficient (ρ_s = 0.55), statistically significant (p-value < 0.0001) with PC_t, followed by the cost of production of the first stage (ρ_s = 046).

Figure 1 shows how the stochastic value of TP_c changes according to the sampling of production cost values for each cutting stage (PC_t). Therefore, the CC_0 is the input with the greatest effect on the TP_c, because it presents the steepest line when compared to the lines of the other inputs.

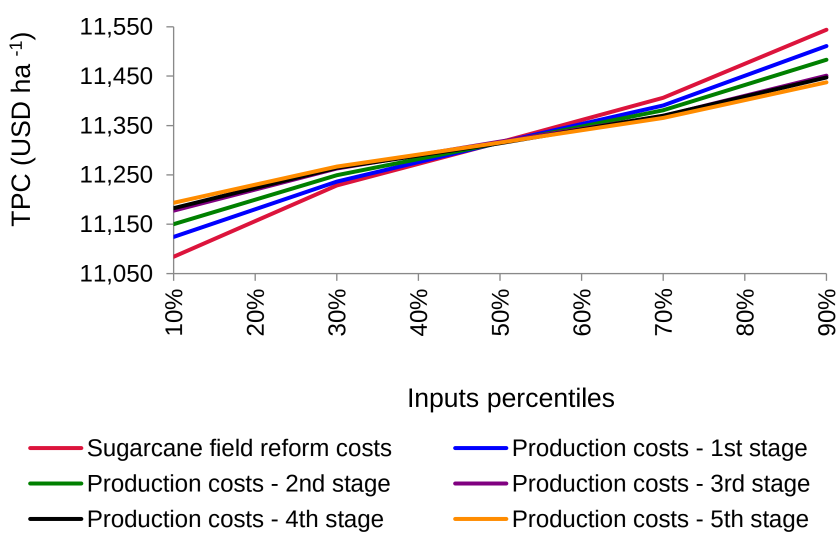

Fig. 1. Modal value of TP_c versus percentage change in CC_0 and PC_t

Cutting, loading, and transportation cost was the main component of production costs, accounting for 43.0% of each cutting stage cost. However, this expenditure was

47.2% in the first stage. This fact is explained by the higher productivity obtained at this stage. The higher the productivity of sugarcane, the higher the costs of cutting, loading, and transportation (Kaneko *et al.* 2009), consequently, in the last stage, this component represented 40.0% of the production cost.

The variable whose change has the greatest impact on profitability is the sugarcane price (Oliveira *et al.* 2011). In this way, the mean values ($\bar{x}$) of the sugarcane price on the conveyor belt (Table 2) decreased from 1st stage to 4th stage, with a slight increase in the 5th. Therefore, it is necessary to adopt actions at the beginning of the harvest that can assure the sugarcane price to be paid to the producer, so that there is no compromise of the economic feasibility of sugarcane cultivation for bioethanol production from sugar cane molasses.

Table 2. Mean Value ($\bar{x}$) and Standard Deviation (SD) of the Sugarcane Price on the Conveyor Belt Paid during the Five Cutting Stages of Sugarcane Cultivated in a Region of Brazil

Sugarcane Price on the Conveyor Belt (USD t^{-1})	$\bar{x}$	SD
1st stage	29.25	1.79
2nd stage	26.70	1.64
3rd stage	23.89	1.46
4th stage	23.20	1.42
5th stage	26.22	1.61

Risk-based Decision Analysis

Studying joint behavior and quantifying the association between two variables is extremely important to predict the value of the other (Devore 2011; Triola 2018). In this way, the tornado graph (Fig. 2) that allows classifying the parameters according to their influence (Li *et al.* 2015), shows the relationship among the five most representative variables of the stochastic model, of which four have a positive relationship with NPV.

The only variable that presented negative correlation was sugarcane field reform costs. However, the correlation coefficient of this variable can be considered low (Rowntree 1981).

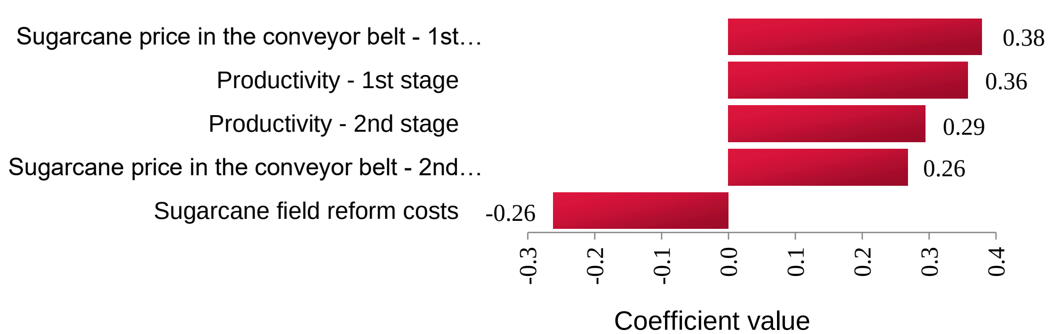

Fig. 2. Spearman order correlation coefficients of the five input variables that most influence the NPV of sugarcane cultivation for bioethanol production

Highly leveraged firms are more likely to use NPV and perform sensitivity and simulation analyses. Thus, the NPV is taken as a stochastic dependable variable, for the uncertainty is taken into account for the input variables to affect it (Graham and Harvey

2001; Franco-Sepulveda *et al.* 2017). Therefore, more robust information is obtained that allows decision makers to rely on results acquired through statistical techniques.

In this case, based on the minimum acceptable rate of return calculated using CAPM, which was 11.3%, the NPV modal value was 1,759.49 USD, and therefore, the project is acceptable for the weighted cut stages (Shane *et al.* 2017; Yasrebi *et al.* 2017). Moreover, the probability of the economic return being greater than zero is 99.0%, as can be seen in the cumulative frequency curve (Fig. 3).

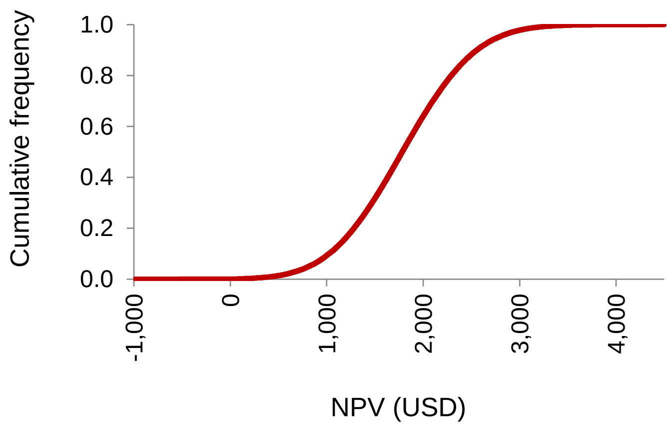

Fig. 3. Cumulative frequency of NPV for the analysis of investments of sugarcane cultivation for bioethanol production

To provide an estimate with greater accuracy and reliability, a 90% confidence interval (1,783.47 USD; 1,789.67 USD) was constructed for the NPV mean value (1,786.57 USD), which presented an extension that can be considered small (3.10 USD), corroborating the estimate accuracy.

Some crops, such as sugarcane, require cash outflows demanded by cultural practices over the lifetime of the crop, so the project will present unconventional cash flows. These cash flows, if analyzed by the internal rate of return (IRR), may present different solutions. To correct this structural problem and others arising from the assumption of reinvestments, MIRR, discovered in the 18th century, is the most reliable, as well as realistic (Lin 1976; Kierulff 2008; Satyasai 2009; Mackevicius and Vladislav 2010).

From this perspective, the modal value of MIRR was 16.3%; therefore, 5% higher than MARR, which indicates that the investment project is acceptable. Additionally, the probability of MIRR being higher than MARR is 89.1%. In order to obtain a perception of the measures of position, dispersion, and distribution tails of the respective variables, the box-plot, with the central position represented by the mean and the dispersion by the interquartile distance, is shown in Fig. 4. Moreover, the variables have symmetric distributions.

PI is an assessment method of the economic efficiency of the investment project, which takes into account the ratio of economic revenue and capital investment (Evans and Guthrie 2012; Miklovičová *et al.* 2013). So, it assures decision-makers the definition of economic profitability. Therefore, the modal value of PI for sugarcane cultivation for bioethanol production from sugar cane molasses was 1.66, which guarantees the ability of the investment project to take profit, since projects with indices below 1 should be rejected. Accordingly, the probability of PI being less than 1 is 9.7%.

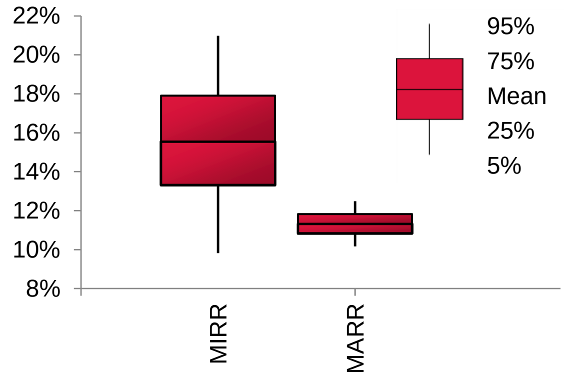

Fig. 4. Box-plot for MIRR and for MARR of sugarcane cultivation for bioethanol production

In addition, using the Bayesian information criterion (BIC) model, which resulted in the lowest value, -775.405, it was observed that the best probability distribution that fit the data generated from this quantitative method of investment analysis was the Normal distribution (Fig. 5).

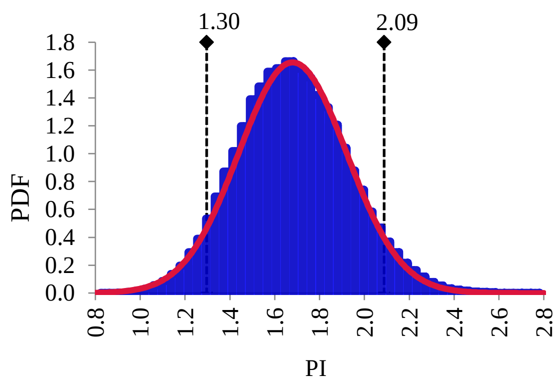

Fig. 5. Probability density function (PDF) of the PI of sugarcane cultivation for bioethanol production

CONCLUSIONS

1. The productivity and the sugarcane price on the conveyor belt of the first two cutting stages exert a greater influence on the economic profitability of the sugarcane crop compared to other variables.
2. Sugarcane cultivation for bioethanol production from sugar cane molasses is economically viable, as shown by the generation of value, with the net present value with high probability to be positive.
3. The probability of the modified internal rate of return being less than the minimum acceptable rate of return may be considered low.
4. The profitability of the sugarcane crop, for the considered cutting stages, is ensured due to the economic contribution shown by the profitability index, which indicates in terms of present value, how much will be the assured return for each unit of US dollars invested.

REFERENCES CITED

Abadie, L. M., and Chamorro, J. M. (2013). *Investment in Energy Assets under Uncertainty*, Springer, London, England.

Agrianual. (2016). "Anuário da agricultura brasileira," Informa Economics FNP, São Paulo, Brazil.

Alexander, C., and Sarabia, J. M. (2012). "Quantile uncertainty and value-at-risk model risk," *Risk Analysis* 32(8), 1293-1308. DOI: 10.1111/j.1539-6924.2012.01824.x

Banco Central do Brasil. (2017). "Conversão de Moedas, " http://www4.bcb.gov.br/pec/conversao/conversao.asp. Accessed 4 Sep 2017.

Bastos, K. J. J. Z., Landell, M. G. A., and Miranda, E. S. (2016). "Influência da produtividade da cana-de-açúcar no custo do corte mecanizado," *Rev. iPecege.* 2(4), 42-59.

Bizzo, W. A., Lenço, P. C., Carvalho, D. J., and Veiga, J. P. S. (2014). "The generation of residual biomass during the production of bio-ethanol from sugarcane, its characterization and its use in energy production," *Renew. Sust. Energ. Rev.* 29, 589-603. DOI: 10.1016/j.rser.2013.08.056

Burnquist, H. L. (1999). "O sistema de remuneração da tonelada de cana pela qualidade-CONSECANA," *Preços Agr.* 14(148), 14-16.

Dalri, A. B., and Cruz, R. L. (2008). "Produtividade da cana-de-açúcar fertirrigada com N e K via gotejamento subsuperficial," *Eng. Agr.* 28(3), 516-524. DOI: 10.1590/S0100-69162008000300012

Devore, J. L. (2011). *Probability and Statistics for Engineering and the Sciences*, Cengage Learning, Boston, USA.

El Kasmioui, O., and Ceulemans, R. (2012). "Financial analysis of the cultivation of poplar and willow for bioenergy," *Biomass. Bioenerg.* 43, 52-64. DOI: 10.1016/j.biombioe.2012.04.006

Evans, L., and Guthrie, G. (2012). "Price-cap regulation and the scale and timing of investment," *The RAND Journal of Economics* 43(3), 537-561. DOI: 10.1111/j.1756-2171.2012.00185.x

Franco-Sepulveda, G., Campuzano, C., and Pineda, C. (2017). "NPV risk simulation of an open pit gold mine project under the O'Hara cost model by using GAs," *International Journal of Mining Science and Technology* 27(3), 557-565. DOI: 10.1016/j.ijmst.2017.03.004

Graham, J. R., and Harvey, C. R. (2001). "The theory and practice of corporate finance: Evidence from the field," *J. Financial Economics* 60(2–3), 187-243. DOI: 10.1016/S0304-405X(01)00044-7

Instituto de Economia Agrícola. (2017). "Valor de Terra Nua," http://ciagri.iea.sp.gov.br/nia1/precor.aspx?cod_tipo=1&cod_sis=8. Accessed 30 Aug 2017.

Jonker, J. G. G., Van Der Hilst, F., Junginger, H. M., Cavalett, O., Chagas, M. F., and Faaij, A. P. C. (2015). "Outlook for ethanol production costs in Brazil up to 2030, for different biomass crops and industrial technologies," *Appl. Energ.* 147, 593-610. DOI: 10.1016/j.apenergy.2015.01.090

Kaneko, F. H., Tarsitano, M. A. A., Rapassi, R. M. A., Chioderoli, C. A., and Nakayama, F. T. (2009). "Análise econômica da produção de cana-de-açúcar considerando-se a terceirização das operações agrícolas: O caso de um produtor," *Pesq. Agropec. Trop.* 39(3), 266-270.

Kierulff, H. (2008). "MIRR: A better measure," *Business Horizons* 51(4), 321-329. DOI: 10.1016/j.bushor.2008.02.005

Li, Q., and Hu, G. (2016). "Techno-economic analysis of biofuel production considering logistic configurations," *Bioresource Technol.* 206, 195-203. DOI: 10.1016/j.biortech.2016.01.101

Li, B., Ou, L., Dang, Q., Meyer, P., Jones, S., Brown, R., and Wright, M. (2015). "Techno-economic and uncertainty analysis of in situ and ex situ fast pyrolysis for biofuel production," *Bioresource Technol.* 196, 49-56. DOI: 10.1016/j.biortech.2015.07.073

Lin, S. A. Y. (1976). "The modified internal rate of return and investment criterion," *The Engineering Economist* 21(4), 237-247. DOI: 10.1080/00137917608902796

Mackevicius, J., and Vladislav, T. (2010). "Evaluation of investment projects in case of conflict between the internal rate of return and the net present value method," *Ekonomika Journal* 89(4), 116-130.

Mendes, J. T. G., and Padilha Junior, J. B. (2007). *Agronegócio: Uma abordagem econômica*, Pearson Prentice Hall, São Paulo, Brazil.

Miklovičová, J., Miklovičová, S., Ladislav, M., and Irena, F. (2013). "Analysis of farms and commercial companies operating activities in Slovakia based on quantification of chosen investments method," *International Journal of Business and Marketing Management* 1(1), 9-17.

Oliveira, A. C. S., Rubim, R. F., Fernandes, P. G., Prellwitz, W. P. V., and Azevedo, P. H. D. A. M. (2011). "Avaliação econômica de cana-de-açúcar em sistema de plantio direto em comparação ao convencional em Campos dos Goytacazes-RJ," *Rev. Vértices* 13(1), 101-110.

Oliveira, W. X., Patarroyo, A. M., and Martins, P. C. (2015). "Managing costs of production and processing," in: *Sugarcane: Agricultural Production, Bioenergy and Ethanol*, F. Santos, A. Borém, and C. Caldas (eds.), Academic Press, San Diego, USA, 439-453.

Ponisio, L. C., and Ehrlich, P. R. (2016). "Diversification, yield and a new agricultural revolution: Problems and prospects," *Sustainability-Basel* 8(11), 1118. DOI: 10.3390/su8111118

Prasara-A, J., and Gheewala, S. H. (2016). "Sustainability of sugarcane cultivation: Case study of selected sites in north-eastern Thailand," *J. Cleaner Production*, Special Volume: Green and Sustainable Innovation for Cleaner Production in the Asia-Pacific Region, 134, Part B, 613-622. DOI: 10.1016/j.jclepro.2015.09.029

Rajabi, M. M., Ataie-Ashtiani, B., and Janssen, H. (2015). "Efficiency enhancement of optimized Latin hypercube sampling strategies: Application to Monte Carlo uncertainty analysis and meta-modeling," *Adv. Water Resour.* 76, 127-139. DOI: 10.1016/j.advwatres.2014.12.008

Rhein, A. F. L., Pincelli, R. P., Arantes, M. T., Dellabiglia, W. J., Kölln, O. T., Silva, M. de A. (2016). "Technological quality and yield of sugarcane grown under nitrogen doses via subsurface drip fertigation," *Rev. Bras. Eng. Agr. Amb.* 20(3), 209-214. DOI: 10.1590/1807-1929/agriambi.v20n3p209-214

Rowntree, D. (1981). *Statistics without Tears: An Introduction for Non-mathematicians*, Penguin, London, England.

Sachs, R. C. C. (2007). "Remuneração da tonelada de cana-de-açúcar no Estado de São Paulo," *Informações Econômicas* 37(2), 55-66.

Santos, H. G., Almeida, J. A., Oliveira, J. B., Lumbreras, J. F., Anjos, L. H. C., Coelho,

M. R., Jacomine, P. K. T., Cunha, T. J. F., and Oliveira, V. Á. (2013). *Sistema brasileiro de classificação de solos,* Embrapa Solos, Brasília, Brazil.

Satyasai, K. (2009). "Application of modified internal rate of return method for watershed evaluation," *Agricultural Economics Research Review* 1(1), 401-406.

Sawaengsak, W., and Gheewala, S. H. (2017). "Analysis of social and socio-economic impacts of sugarcane production: A case study in Nakhon Ratchasima province of Thailand," *J. Cleaner Production, Green Sustainable Innovation and Applications* 142, Part 3, 1169-1175. DOI: 10.1016/j.jclepro.2016.08.148

Schwabe, O., Shehab, E., and Erkoyuncu, J. (2015). "Geometric quantification of cost uncertainty propagation: A case study," *Proc. CIRP*. 37, 158-163. DOI: 10.1016/j.procir.2015.08.078

Shane, A., Gheewala, S. H., and Phiri, S. (2017). "Rural domestic biogas supply model for Zambia," *Renew. Sust. Energ. Rev.* 78, 683-697. DOI: 10.1016/j.rser.2017.05.008

Shields, M. D., and Zhang, J. (2016). "The generalization of Latin hypercube sampling," *Reliab. Eng. Syst. Safe.* 148, 96-108. DOI: 10.1016/j.ress.2015.12.002

Shrader-Frechette, K. S. (1986). "The conceptual risks of risk assessment," *IEEE Technol. Soc. Mag.* 5(2), 4-11. DOI: 10.1109/MTAS.1986.5010007

Signor, D., Zani, C. F., Paladini, A. A., Deon, M. D., and Cerri, C. E. P. (2014). "Carbon stocks and quality of soil organic matter in sugarcane fields," *Rev. Bras. Ciênc. Solo* 38(5), 1402-1410. DOI: 10.1590/S0100-06832014000500005

Silva, M. A., Arantes, M. T., Rhein, A. F. L., Gava, G. J. C., and Kolln, O. T. (2014). "Yield potential of sugarcane under drip irrigation in function of varieties and crop cycles," *Rev. Bras. Eng. Agr. Amb.* 18(3), 241-249. DOI: 10.1590/S1415-43662014000300001

Simões, D., Mosquera A. D., Batistela, G. C., Passos, J. R. S., and Fenner, P. T. (2016). "Quantitative analysis of uncertainty in financial risk assessment of road transportation of wood in Uruguay," *Forests* 7(7), 130. DOI: 10.3390/f7070130

Sultania, G., Bhavathrathan, B. K., and Patil, G. R. (2016). "Quantifying risk due to capacity uncertainty on urban road networks," *Transportation Research Procedia, International Conference on Transportation Planning and Implementation Methodologies for Developing Countries (12th TPMDC) Selected Proceedings*, IIT Bombay, Mumbai, India, pp. 539-547. DOI: 10.1016/j.trpro.2016.11.108

Triola, M. F. (2018). Elementary statistics, Pearson, London, England.

Yasrebi, A. B., Hezarkhani, A., and Afzal, P. (2017). "Application of present value-volume (PV-V) and NPV-cumulative total ore (NPV-CTO) fractal modelling for mining strategy selection," *Resources Policy* 53, 384-393. DOI: 10.1016/j.resourpol.2017.07.011

Zhang, K., Liu, J., Wang, E., and Wang, J. (2017). "Quantifying risks with exact analytical solutions of derivative pricing distribution," *Physica A.* 471, 757-766. DOI: 10.1016/j.physa.2016.12.044

Article submitted: March 9, 2018; Peer review completed: July 7, 2018; Revised version received: July 8, 2018; Accepted: July 9, 2018; Published: July 11, 2018.
DOI: 10.15376/biores.13.3.6497-6509